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(54) Titre : MINOBODIES J591 ET CYS-DIABODIES POUR LE CIBLAGE DE L'ANTIGENE MEMBRANAIRE  
SPECIFIQUE DE LA PROSTATE HUMAINE (PSMA), ET PROCEDES D'UTILISATION  
(54) Title: J591 MINIBODIES AND CYS-DIABODIES FOR TARGETING HUMAN PROSTATE SPECIFIC MEMBRANE  
ANTIGEN (PSMA) AND METHODS FOR THEIR USE

(57) **Abrégé/Abstract:**

In one embodiment, a minibody monomer that binds PSMA is provided. The minibody monomer is encoded by a nucleotide sequence comprising, from N-terminus to C-terminus, an scFv sequence that can bind PSMA, an artificial hinge sequence, and a human IgG CH3 sequence. In another embodiment, a CysDB monomer that binds PSMA is provided. The CysDB monomer may be encoded by a nucleotide sequence comprising, from N-terminus to C-terminus, an scFv sequence that can bind PSMA and a cysteine tail. In other embodiments, methods for diagnosing or treating a cancer associated with PSMA expression in a subject are provided.

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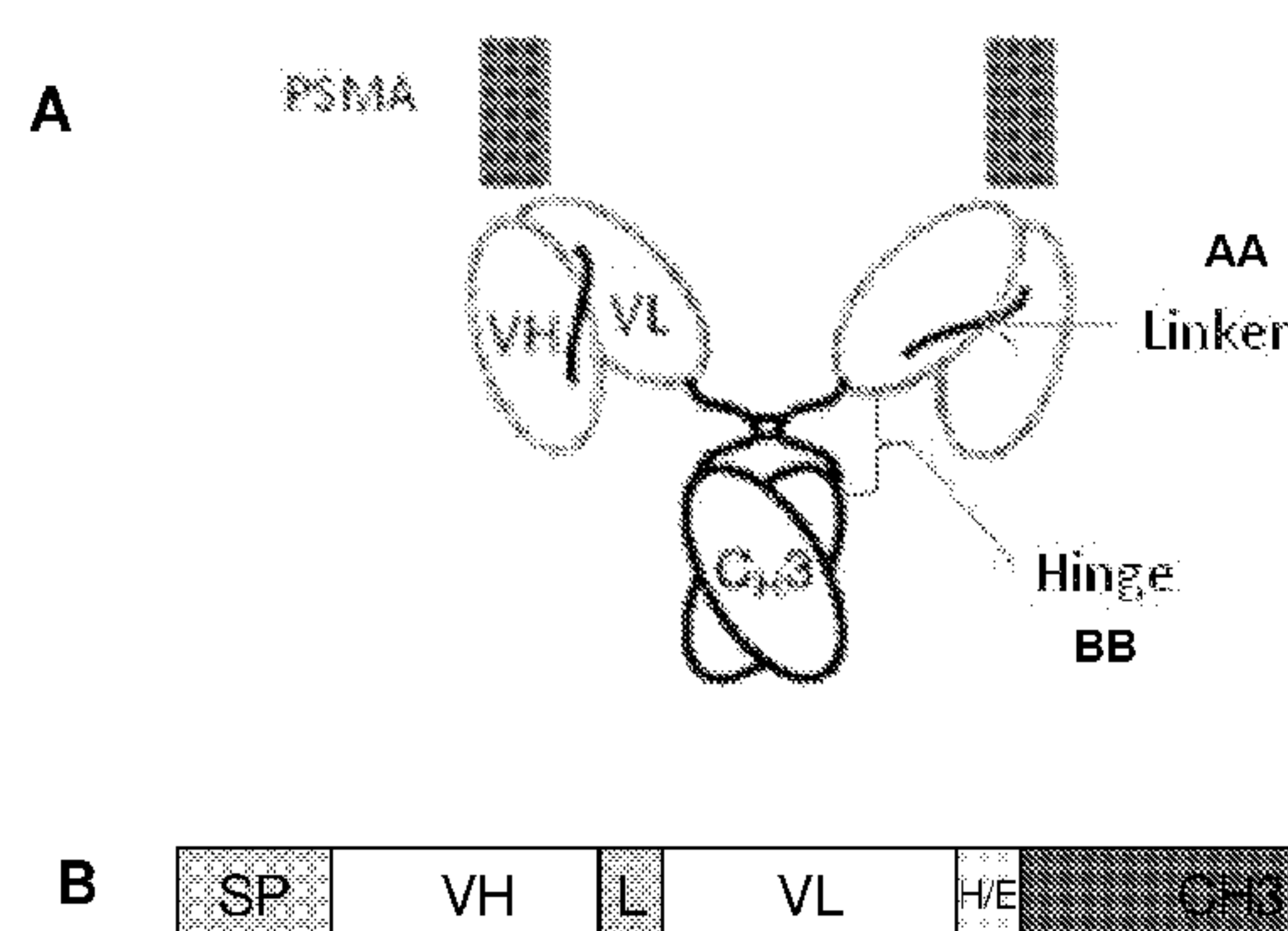


Fig. 1

(57) Abstract: In one embodiment, a minibody monomer that binds PSMA is provided. The minibody monomer is encoded by a nucleotide sequence comprising, from N-terminus to C-terminus, an scFv sequence that can bind PSMA, an artificial hinge sequence, and a human IgG CH3 sequence. In another embodiment, a CysDB monomer that binds PSMA is provided. The CysDB monomer may be encoded by a nucleotide sequence comprising, from N-terminus to C-terminus, an scFv sequence that can bind PSMA and a cysteine tail. In other embodiments, methods for diagnosing or treating a cancer associated with PSMA expression in a subject are provided.

## **J591 MINIBODIES AND CYS-DIABODIES FOR TARGETING HUMAN PROSTATE SPECIFIC MEMBRANE ANTIGEN (PSMA) AND METHODS FOR THEIR USE**

### **STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH**

**[0001]** This invention was made with government support under Contract No. HHSN261200900051C, awarded by the National Cancer Institute (NCI). The government has certain rights in the invention.

### **PRIORITY CLAIM**

This application claims the benefit of U.S. Provisional Application No. 61/266,134, filed December 2, 2009.

### **BACKGROUND**

**[0002]** Advances in antibody engineering have enabled the development of various antibody fragments featuring different pharmacokinetic and binding properties (Wu et al 2005, Wu et al 2008, Wu et al 2009). A minibody is an antibody format which features a smaller molecular weight (~80kD) than the full-length antibody while maintaining the bivalent binding property against an antigen (Hu et al 1996). Because of its smaller size, the minibody features faster clearance from the system and enhanced penetration when targeting tumor tissue. With the ability for strong targeting combined with rapid clearance, the minibody is an optimized antibody format that may be used for diagnostic imaging (Wu et al 2005). Since the discovery of the first minibody against the tumor-associated target CEA, many minibodies have been developed against different cancer targets for preclinical diagnostic imaging including human epidermal growth factor receptor-2 (HER2) in breast cancer, B-lymphocyte antigen CD20 in non-Hodgkins' lymphoma, and prostate stem cell antigen (PSCA) in prostate cancer (Hu et al 1996, Leyton et al 2008, Olafsen et al 2004, Olafsen et al

2009). For example, an  $^{123}\text{I}$ -labeled CEA minibody has been evaluated in the clinic for imaging patients with colorectal cancer by SPECT and similar studies have been performed with an  $^{111}\text{In}$ -DOTA labeled minibody (Wong et al 2004). The development of novel imaging agents is particularly critical for the diagnosis, management, and treatment of specific cancers which are poorly imaged with current technology such as prostate cancer.

**[0003]** The development of imaging agents for all types of cancer is needed to enable the targeting, staging, and monitoring of the disease. Current methods for diagnostic imaging of prostate cancer remain relatively inaccurate. With an estimated 234,460 new cases and 27,350 deaths in 2006, an imaging agent capable of accurately diagnosing, staging, and monitoring prostate cancer is needed (Olson et al 2007).

**[0004]** Prostate Specific Membrane Antigen (PSMA), a cell-surface biomarker that is associated with prostate cancer (Slovin 2005), is a single-pass Type II transmembrane protein possessing glutamate carboxypeptidase activity, although the functional role of PSMA is not well understood (Olson et al 2007). Expression of PSMA is relatively limited in normal tissues outside of the prostate including the brain, small intestines, liver, proximal kidney tubules, and salivary gland (Olson et al 2007).

**[0005]** PSMA expression in prostate cancer increases with tumor aggressiveness and is the highest in high-grade tumors, metastatic lesions, and androgen-independent disease (Olson et al 2007). Therefore, PSMA is a cancer biomarker that is a good candidate for targeting by an imaging agent. PSMA expression is also upregulated in the neovasculature of many non-prostatic solid tumors including lung, colon, breast, renal, liver and pancreatic carcinomas as well as sarcomas and melanoma (Olson et al 2007).

**[0006]** Full-length antibodies that target PSMA have been developed, some of which are in various stages of preclinical and clinical development (Olson et al 2007). PSMA was originally defined by a murine antibody (mAb), 7E11, which recognized an intracellular epitope of PSMA (Olson et al 2007). The 7E11 mAb was later developed into a FDA-approved SPECT imaging agent called Prostascint™ for the detection and

imaging of prostate cancer in soft tissue (Olson et al 2007). However, since 7E11 recognizes an intracellular epitope, Proscint is a relatively poor imaging agent which is limited to detecting necrotic tumor tissue (Olson et al 2007). Having the pharmacokinetic properties of a full-length antibody, Proscint also requires a long period of time between injection and imaging (Olson et al 2007). Furthermore, Proscint is a murine antibody which elicits strong immune responses that prevent multiple dosing (Olson et al 2007).

**[0007]** Another full-length antibody that targets PSMA, J591, was discovered and subsequently deimmunized, the deimmunized version known as huJ591 (Liu et al 1997, Bander et al 2003). The deimmunized huJ591 is an anti-human PSMA antibody that recognizes and binds an extracellular epitope on PSMA (Bander et al 2003). The huJ591 antibody is being developed as a potential radioimmunotherapy agent against prostate cancer. In Phase I trials, DOTA-conjugated huJ591 antibody labeled with gamma emitting isotopes Indium 111 and Lutetium 177 demonstrated excellent targeting to metastatic sites, no immunogenicity, and multiple doses were well tolerated (Bander et al 2003, Milowsky et al 2004, Bander et al 2005, Olson et al 2007). Beyond prostate cancer, Phase I studies with <sup>111</sup>In-DOTA huJ591 demonstrated specific targeting of tumor neovasculature of advanced solid tumors (Milowsky et al 2007).

## SUMMARY

**[0008]** In one embodiment, a minibody that binds PSMA is provided. According to this embodiment, the minibody is encoded by a nucleotide sequence comprising, from N-terminus to C-terminus, an scFv sequence that can bind prostate specific membrane antigen (PSMA), an artificial hinge sequence, and a human IgG1 CH3 sequence. The minibody monomer may also include an N-terminus signal sequence to enable secretion of the minibody when expressed in a cell.

**[0009]** The minibody scFv as described herein comprises a variable heavy domain (VH) linked to a variable light domain (VL) by a linker sequence. In one aspect, the scFv is in a VHVL orientation such that the VH is upstream of the VL. A minibody monomer having such an scFv may have a nucleotide sequence comprising

SEQ ID NO:1 or SEQ ID NO:2. In another aspect, the scFv is in a VLVH orientation such that the VL is upstream of the VH.

**[0010]** The minibody monomer may be expressed by a cell. In such embodiments, a CysDB monomer expressed by a cell may include the amino acid sequence of SEQ ID NO:10 or SEQ ID NO:11.

**[0011]** In another embodiment, a cys-diabody (CysDB) that binds PSMA is provided. According to this embodiment, the CysDB monomer is encoded by a nucleotide sequence comprising, from N-terminus to C-terminus, an scFv sequence that can bind PSMA and a cysteine tail. The CysDB may also include an N-terminus signal sequence to enable secretion of the minibody when expressed in a cell.

**[0012]** The CysDB scFv as described herein comprises a variable heavy domain (VH) linked to a variable light domain (VL) by a linker sequence. In one aspect, the scFv is in a VHVL orientation such that the VH is upstream of the VL. A CysDB monomer having such an scFv may have a nucleotide sequence comprising SEQ ID NO:6 or SEQ ID NO:7. In another aspect, the scFv is in a VLVH orientation such that the VL is upstream of the VH. A CysDB monomer having such an scFv may have a nucleotide sequence comprising SEQ ID NO:8 or SEQ ID NO:9.

**[0013]** The CysDB may be expressed by a cell. In some embodiments, a CysDB expressed by a cell may include the amino acid sequence SEQ ID NO:12, SEQ ID NO:13, SEQ ID NO:14 or SEQ ID NO:15.

**[0014]** In another embodiment, a method for diagnosing a cancer associated with PSMA expression in a subject is provided. Such a method includes administering an anti-PSMA minibody or a cys-diabody conjugated to a diagnostic agent to a subject having or suspected of having a cancer associated with PSMA expression; exposing the subject to an imaging method to visualize the labeled minibody or cys-diabody *in vivo*; and determining that the subject has a cancer associated with PSMA expression when the labeled minibody or cys-diabody localizes to a tumor site.

**[0015]** In another embodiment, a method for treating a cancer associated with PSMA expression in a subject is provided. Such a method includes administering a therapeutically effective amount of a pharmaceutical composition to the subject, the composition comprising an anti-PSMA minibody or an anti-PSMA cys-diabody. In one aspect, the anti-PSMA minibody or anti-PSMA cys-diabody is conjugated to a therapeutic agent.

**[0016]** The cancer associated with PSMA expression in a subject may be lung cancer, colorectal cancer, breast cancer, renal cancer, liver cancer, bladder cancer, pancreatic cancer or melanoma.

**[0017]** A minibody that may be used in the methods as described above may be any suitable minibody as described herein, or may comprise SEQ ID NO:10 or SEQ ID NO:11. A cys-diabody that may be used in methods as described above may be any suitable minibody as described herein, or may comprise SEQ ID NO:12, SEQ ID NO:13, SEQ ID NO:14 or SEQ ID NO:15.

**[0017a]** In accordance with an aspect of the present invention there is provided a minibody comprising:

- an scFv sequence that can bind prostate specific membrane antigen (PSMA), the scFv sequence comprising a variable heavy domain (VH) linked to a variable light domain (VL) by an amino acid linker sequence;

- an artificial hinge sequence comprising a portion of a human IgG1 hinge and a GlySer linker; and

- a human IgG CH3 sequence,

- wherein at least one of:

- a) the VH is a variable heavy domain in SEQ ID NO:10 and the VL is a variable light domain in SEQ ID NO:10; or

- b) the VH is a variable heavy domain in SEQ ID NO:3 and the VL is a variable light domain in SEQ ID NO:17.

**[0017b]** In accordance with a further aspect of the present invention there is provided a minibody comprising:

- an scFv sequence that can bind prostate specific membrane antigen (PSMA), the scFv comprising a variable heavy domain (VH) linked to a variable light domain (VL) by a linker amino acid sequence;
- an artificial hinge sequence comprising a portion of a human IgG1 hinge and a GlySer linker; and
- a human IgG CH3 sequence,

wherein the VH is a variable heavy domain in SEQ ID NO:5 and the VL is a variable light domain in SEQ ID NO:19.

## **BRIEF DESCRIPTION OF THE DRAWINGS**

**[0018]** Figure 1A is a schematic diagram of the J591 Minibody. This diagram depicts the minibody in the VHVL orientation binding the target PSMA.

**[0019]** Figure 1B is a schematic diagram of an expression construct for the J591 minibody in VHVL orientation. SP = signal peptide, VH – variable heavy domain, VL – variable light domain, L – 18 amino acid linker, H./E – artificial hinge/extension, CH3 from human IgG1.

**[0020]** Figure 2 is a comparison between the amino acid sequences of deimmunized (Line 3; SEQ ID NO:5; SEQ ID NO:19), Murine (Line 2; SEQ ID NO:4; SEQ ID NO:18), and Human Composite (Line 1; SEQ ID NO:3; SEQ ID NO:17) J591 V-regions. Highlighted residues along the HC line (Line 1) designate differences between the HC and murine V-regions. Highlighted residues along the deimmunized line (Line 3) designate differences between the deimmunized and the murine V-regions as a result of

the original deimmunization process. The two stars designate the two Prolines introduced by the deimmunization.

**[0021]** Figure 3 is the J591 Human Composite VHVL Minibody nucleotide sequence (SEQ ID NO:1) and corresponding translated amino acid sequence (SEQ ID NO:10).

**[0022]** Figure 4 is the J591 2P VHVL Minibody nucleotide sequence (SEQ ID NO:2) and corresponding translated amino acid sequence (SEQ ID NO:11).

**[0023]** Figure 5 is a schematic diagram of the cys-diabody (CysDB) (A), a schematic diagram of an expression construct for a CysDB in VLVH orientation (B), and a schematic diagram of an expression construct for a CysDB in VHVL orientation (C). SS = signal sequence, VH = variable heavy domain, VL = variable light domain, L linker (may be 5 or 8 amino acids), GGS = cysteine tail (Gly-Gly-Cys).

**[0024]** Figure 6 is the J591 cys-diabody (CysDB) VH-5-VL nucleotide sequence (SEQ ID NO:6) and corresponding translated amino acid sequence (SEQ ID NO:12).

**[0025]** Figure 7 is the J591 cys-diabody (CysDB) VH-8-VL nucleotide sequence (SEQ ID NO:7) and corresponding translated amino acid sequence (SEQ ID NO:13).

**[0026]** Figure 8 is the J591 cys-diabody (CysDB) VL-5-VH nucleotide sequence (SEQ ID NO:8) and corresponding translated amino acid sequence (SEQ ID NO:14).

**[0027]** Figure 9 is the J591 cys-diabody (CysDB) VL-8-VH nucleotide sequence (SEQ ID NO:9) and corresponding translated amino acid sequence (SEQ ID NO:15).

**[0028]** Figure 10 is a Vector Map for pcDNA 3.1/myc-His (-) Versions A, B, C. This expression vector from Invitrogen Corp. features the CMV promoter for mammalian expression and Neomycin resistance for selection.

**[0029]** Figure 11 is a representative Western blot analysis confirming the expression of the J591 minibodies by CHO-K1 cells. Lane 1 corresponds to a Molecular weight marker sample, Lane 2 corresponds to an Empty Vector sample, Lane

3 corresponds to a positive control minibody sample, Lane 4 corresponds to the J591 HC VLVH sample, Lane 5 corresponds to the J591 HC VHVL sample, Lane 6 corresponds to the J591 2P VLVH sample, and Lane 7 corresponds to the J591 2P VHVL sample.

**[0030]** Figure 12A-D are graphs that represent flow cytometry analysis of the J591 minibodies. Histograms plot cell count versus PE signal (FL2-H). Figure 12A shows a graph representing the flow cytometry analysis for the J591 HC VLVH minibody, Figure 12B shows a graph representing the flow cytometry analysis for the J591 HC VHVL minibody, Figure 12C shows a graph representing the flow cytometry analysis for the J591 2P VLVH minibody, and Figure 12D shows a graph representing the flow cytometry analysis for the J591 2P VHVL minibody.

**[0031]** Figure 13 is an SDS-PAGE analysis of the purified J591 minibody. The purified J591 minibody protein was loaded onto the SDS-PAGE gel under non-reducing conditions (lane 1) and reducing conditions (lane 2). The gel was stained with GelCode Blue (Pierce, Thermo Scientific). The minibody was diluted 1/5 for loading on the gel.

**[0032]** Figure 14 is a size exclusion chromatography (SEC) analysis of purified J591 minibody. The graph plots the 220nm UV absorbance (mAU) vs. time (min). 4 $\mu$ g of the J591 minibody was loaded onto a TSK-GEL Super SW3000™ column. A protein molecular weight standard was also run separately on the column to provide reference. The percentage of the aggregate versus the minibody protein (labeled here as monomer) was determined by calculating the area under the curve.

**[0033]** Figure 15 illustrates that the J591 minibody protein binds PSMA by ELISA. 96-well ELISA plates were coated with purified recombinant PSMA protein at 1 $\mu$ g/ml. Purified J591 minibody protein (1, ●) was introduced at a starting concentration of 2 $\mu$ g/ml and serially diluted ten times by third dilutions. Identical dilutions were performed for the negative control minibody (2, ■). Samples were performed in triplicate at each dilution, and the error bars represent standard deviation. Following the primary incubation, bound minibodies were detected using a goat anti-human IgG (Fc

specific) antibody conjugated to alkaline phosphatase and developed with a pNPP solution. Absorbance was detected at 405nm.

**[0034]** Figures 16A-D are graphs that represent flow cytometry analysis, illustrating that the J591 minibody binds PSMA+ cell lines. All histograms plot cell count vs. PE signal (FL2-H). The J591 minibody protein and the negative control minibody (1), both at 20µg/ml, were tested for binding to the PSMA+ cell line LNCaP (A and B) and CWR22rv1 (C and D). Cells were subsequently stained with a secondary anti-human IgG (Fc specific)-PE conjugated antibody.  $1 \times 10^5$  cells/point and analysis was performed with 5,000 events/point. (A) J591 minibody (2) binding LNCaP cells (B) J591-DOTA minibody (2) binding LNCaP cells (C) J591 minibody (2) binding CWR cells (D) J591-DOTA minibody (2) binding CWR cells.

**[0035]** Figure 17 are representative images that show the internalization of J591 minibody in LNCaP cells. LNCaP cells were plated on poly-d-lysine-coated coverslips in 12-well plates. Following 2 days of growth, the cells were pre-chilled for 30 minutes at 4C before incubation with the primary antibody or minibody for 30 minutes at 4C. At the indicated time points after primary incubation, the cells were fixed, permeabilized, and stained with secondary anti-human IgG-Alexa 488. The coverslips were simultaneously mounted on to slides and counterstained with DAPI within the mounting media. Slides were viewed using a 63X oil-immersion lens on a Leica SP2-1P-FCS confocal microscope.

**[0036]** Figure 18 are representative images that show the internalization of J591 minibody in CWR22rv1 cells. CWR22rv1 cells were plated on poly-d-lysine-coated coverslips in 12-well plates. Following 2 days of growth, the cells were pre-chilled for 30 minutes at 4C before incubation with the primary antibody or minibody for 30 minutes at 4C. At the indicated time points post-primary incubation, the cells were fixed, permeabilized, and stained with secondary anti-human IgG-Alexa 488. The coverslips were simultaneously mounted on to slides and counterstained with DAPI within the mounting media. Slides were viewed using a 63X oil-immersion lens on a Leica SP2-1P-FCS confocal microscope.

**[0037]** Figure 19 is a graph illustrating uptake and retention of cell-associated radioactivity of  $^{131}\text{I}$ -labelled and  $^{111}\text{In}$ -DOTA labelled J591 minibody. The uptake and retention of cell-associated radioactivity over time upon binding to CWR22rv1 cells. The radioactivity from the cell membrane, cell lysate (internalized), and total (membrane + internalized) fractions are expressed as counts per minute (cpm). CWR22rv1 cells were seeded into 24-well plates at  $5 \times 10^5$  cells/well the day before the experiment. Cells were pre-chilled at 4C before incubation with an excess of (A)  $^{131}\text{I}$ -labelled or (B)  $^{111}\text{In}$ -DOTA labelled J591 minibody. At each time point, the supernatant containing the radiolabeled minibody was removed, the cells were stripped with an acidic glycine buffer to obtain the membrane fraction, and the cells were lysed. Each time point was performed in triplicate. The Y-bars represent standard deviation.

**[0038]** Figure 20 is a graph comparing cell-associated radioactivity of  $^{131}\text{I}$  labelled versus  $^{111}\text{In}$ -DOTA labelled J591 minibody. The total cell-associated radioactivity (membrane + internalized) expressed as a percentage of the initial cell-associated radioactivity over time upon binding to CWR22rv1 cells. This plot shows both the  $^{131}\text{I}$ -labelled (bottom line) and the  $^{111}\text{In}$ -DOTA labelled J591 minibody (top line).

**[0039]** Figure 21 illustrates representative serial microPET/CT images of a mouse bearing CWR22rv1 and PC3 xenografts injected with  $^{64}\text{Cu}$ -DOTA-J591 minibody. A representative mouse was serially scanned at multiple times postinjection. The CWR22rv1 tumor is depicted as the (+) tumor and the PC3 tumor as the (-) tumor. (A) CT scan at 4 hours postinjection. Coronal and tranverse planes are shown. (B) PET/CT overlay image at 4 hours postinjection. Coronal and transverse planes are shown. (C) Coronal PET/CT overlay 3D projection of the representative mouse at 4 hours postinjection (D) Coronal PET/CT overlay 3D projection of the representative mouse at 43 hours postinjection.

**[0040]** Figure 22 is a bar graph illustrating the biodistribution of  $^{64}\text{Cu}$ -DOTA-J591 minibody at 19 hours and 43 hours post-injection. Graph plotting the biodistribution of the  $^{64}\text{Cu}$ -DOTA-J591 minibody in the xenograft tumors and selected normal tissues of interest. Biodistribution is plotted as % of the injected dose divided by weight in grams

(%ID/g). Each data point represents the average %ID/g for the group of mice at 19 hrs (n =8) and 43 hrs postinjection (n =4). The error bars represent the standard deviation.

**[0041]** Figure 23 is illustrates representative serial microPET images of a mouse bearing CWR22rv1 and PC3 xenografts injected with  $^{124}\text{I}$ -J591 minibody. A representative mouse was serially scanned at multiple times postinjection. The CWR22rv1 tumor is depicted as the (+) tumor and the PC3 tumor as the (-) tumor. (A) CT scan at 4 hours postinjection. Coronal and tranverse planes are shown. (B) PET/CT overlay image at 4 hours postinjection. Coronal and transverse planes are shown. (C) Coronal PET/CT overlay images at 4, 20, and 44 hours postinjection.

**[0042]** Figure 24 is a bar graph illustrating the biodistribution of  $^{124}\text{I}$ -J591 minibody at 19 hours and 44 hours post-injection. Graph plotting the biodistribution of the  $^{124}\text{I}$ -J591 minibody in the xenograft tumors and selected normal tissues of interest. Biodistribution is expressed as % of the injected dose divided by weight in grams (%ID/g). Each data point represents the average %ID/g for the group of mice (n =4 at 19 hours, n =2 at 44 hours) at 19 hrs and 44 hrs postinjection. The error bars represent the standard deviation.

**[0043]** Figure 25 is a bar graph illustrating the expression level of the following minibody variants in transient transfected CHO-K1 cells: (1) J591 HC VLVH minibody (J591 VLVH Mb), (2) J591 HC VHVL minibody (J591 VHVL Mb), (3) J591 2P VLVH minibody (J591 VLVH\*\* Mb) and (4) J591 2P VHVL minibody (J591 VHVL\*\* Mb). The huJ591 HC VHVL exhibited the highest expression (6.7  $\mu\text{g/mL}$ ) from transient transfection.

**[0044]** Figure 26 is a bar graph showing the biodistribution ratios (i.e., positive tumor to tissue ratios) at 4 hours, 20 hours and 43 hours after injection of the  $^{64}\text{Cu}$ -DOTA-J591 minibody. The biodistribution ratios included ratios of positive tumor (Pos) compared to liver (Liv), kidneys (Kid) and soft tissue (Soft). Error bars represent mean standard errors (SEM).

**[0045]** Figure 27 is a bar graph showing the biodistribution ratios (i.e., positive tumor to tissue ratios) at 4 hours, 20 hours and 43 hours after injection of the  $^{124}\text{I}$ -J591 minibody. The biodistribution ratios included ratios of positive tumor (Pos) compared to liver (Liv), kidneys (Kid) and soft tissue (Soft). Error bars represent mean standard errors (SEM).

## **DETAILED DESCRIPTION**

**[0046]** The disclosure is directed to an antibody or functional antibody fragment that targets prostate specific membrane antigen (PSMA). The PSMA antibody or functional antibody fragment thereof may be conjugated to a substance such as a diagnostic agent, a therapeutic agent or a nanoparticle to form an anti-PSMA conjugate. Also disclosed are methods that include the use of the PSMA antibody, the functional PSMA antibody fragment or the anti-PSMA conjugate for diagnosing, visualizing, monitoring, or treating cancer or other conditions associated with overexpression of PSMA.

### **PSMA Antibodies and functional fragments thereof**

**[0047]** PSMA antibodies or a functional PSMA antibody fragments are provided herein according to the embodiments described herein. A PSMA antibody or functional antibody fragment is a molecule that includes one or more portions of an immunoglobulin or immunoglobulin-related molecule that specifically binds to, or is immunologically reactive with a PSMA. The term modified antibody includes, but is not limited to genetically engineered or otherwise modified forms of immunoglobulins, such as intrabodies, chimeric antibodies, fully human antibodies, humanized antibodies, and heteroconjugate antibodies (e.g., bispecific antibodies, diabodies, triabodies, and tetrabodies). The term functional antibody fragment includes one or more antigen binding fragments of antibodies alone or in combination with other molecules, including, but not limited to Fab', F(ab')<sub>2</sub>, Fab, Fv, rIgG, scFv fragments, single domain fragments, peptibodies, minibodies and cys-diabodies. The term scFv refers to a single chain Fv antibody in which the variable domains of the heavy chain and of the light chain of a traditional two chain antibody have been joined to form one chain.

**[0048]** In one embodiment, the modified antibody or functional antibody fragment is an anti-PSMA minibody. In one embodiment, the anti-PSMA antibody is a J591 minibody. The anti-PSMA minibody has an anti-PSMA antibody fragment with optimized pharmacodynamic properties for *in vivo* imaging and biodistribution as described below. A “minibody” is a homodimer, wherein each monomer is a single-chain variable fragment (scFv) linked to a human IgG1 CH3 domain by a linker, such as a hinge sequence. In one embodiment, the hinge sequence is a human IgG1 hinge sequence (EPKSCDKTHTCPPCPAPELLGGP; SEQ ID NO:16). In another embodiment, the hinge sequence is an artificial hinge sequence. The artificial hinge sequence may include a portion of a human IgG1 hinge and a GlySer linker sequence. In one embodiment, the artificial hinge sequence includes approximately the first 14 or 15 residues of the human IgG1 hinge followed by a GlySer linker sequence that is 8, 9 or 10 amino acids in length. In another embodiment, the artificial hinge sequence includes approximately the first 15 residues of the IgG1 hinge followed by a GlySer linker sequence that is 10 amino acids in length.

**[0049]** The scFv may have a VHVL or a VLVH orientation, wherein a VHVL orientation means that the variable heavy domain (VH) of the scFv is upstream from the variable light region (VL) and a VLVH orientation means that the VL of the scFv is upstream from the VH. As used herein, “upstream” means toward the N-terminus of an amino acid or toward the 5' end of a nucleotide sequence. The VH and VL are linked to each other by an amino acid linker sequence. The amino acid linker may be any suitable length. In one embodiment, the linker is Gly-Ser-rich and approximately 15-20 amino acids in length. In another embodiment, the linker is Gly-Ser rich and is 18 amino acids in length.

**[0050]** According to the embodiments described herein, each monomer of the anti-PSMA minibody may be encoded by a nucleotide sequence that includes the following elements, from N-terminus to C-terminus: (a) an scFv sequence that can bind PSMA, (b) an artificial hinge sequence, and (c) a human IgG CH3 sequence. The minibodies may be expressed by a cell, a cell line or other suitable expression system as described herein. Thus, a signal sequence may be fused to the N-terminus of the

scFv to enable secretion of the minibody when expressed in the cell or cell line. In some embodiments, the nucleotide sequence is SEQ ID NO:1 or SEQ ID NO:2. When expressed by a cell or cell line, the nucleotide is transcribed and translated into an amino acid sequence. In some embodiments, the expressed amino acid sequence is SEQ ID NO:10 or SEQ ID NO:11.

**[0051]** In another embodiment, the modified antibody or functional antibody fragment is an anti-PSMA cys-diabody (CysDB) is provided. A "diabody" comprises a first polypeptide chain which comprises a heavy (VH) chain variable domain connected to a light chain variable domain (VL) on the first polypeptide chain (VH-VL) connected by a peptide linker that is too short to allow pairing between the two domains on the first polypeptide chain and a second polypeptide chain comprising a light chain variable domain (VL) linked to a heavy chain variable domain VH on the second polypeptide chain (VL-VH) connected by a peptide linker that is too short to allow pairing between the two domains on the second polypeptide chain. The short linkages force chain pairing between the complementary domains of the first and the second polypeptide chains and promotes the assembly of a dimeric molecule with two functional antigen binding sites. Therefore, a peptide linker may be any suitable length that promotes such assembly, for example, between 5 and 10 amino acids in length. As described further below, some cys-diabodies may include a peptide linker that is 5 or 8 amino acids in length. The anti-PSMA CysDB is a homodimer antibody format formed with two identical monomers that include single chain Fv (scFv) fragments with an approximate molecular weight of 55 kDa. In one embodiment, the anti-PSMA is a J591 CysDB. Like the anti-PSMA minibodies described above, the anti-PSMA CysDBs described herein have an anti-PSMA antibody fragment with optimized pharmacodynamic properties that may be used for *in vivo* imaging and biodistribution.

**[0052]** According to the embodiments described herein, each monomer of a CysDB may be encoded by a nucleotide sequence that includes the following elements, from N-terminus to C-terminus: (a) an scFv sequence that can bind PSMA and (b) a cysteine tail. The CysDBs may be expressed by a cell or a cell line as described herein. Thus, a signal sequence may be fused to the N-terminus of the scFv to enable secretion

of the minibody when expressed in the cell or cell line. In some embodiments, the nucleotide sequence is SEQ ID NO:6, SEQ ID NO:7, SEQ ID NO:8 or SEQ ID NO:9. When expressed by a cell or cell line, the nucleotide is transcribed and translated into an amino acid sequence. In some embodiments, the expressed amino acid sequence is SEQ ID NO:12, SEQ ID NO:13, SEQ ID NO:14 or SEQ ID NO:15.

**[0053]** According to some embodiments, the CysDB scFv sequence is similar to the minibody scFv sequences described above scFv. Thus, the scFv may have a VHVL or a VLVH orientation, wherein a VHVL orientation means that the variable heavy domain (VH) of the scFv is upstream from the variable light region (VL) and a VLVH orientation means that the VL of the scFv is upstream from the VH. The antibody variable regions are linked together by a GlySer linker as described above. A Cysteine tail (Gly-Gly-Cys), is added at the C-terminus. This Cysteine tail allows the diabody complex to form covalent Cysteine bonds and provides the option for available sulfur residues for site-specific conjugation of functional moieties such as radiolabels.

**[0054]** Multiple CysDBs have been successfully engineered from various parental antibodies against different targets including CEA, Her2 (trastuzumab/Herceptin®), PSCA, and CD20 (rituximab/Rituxan®). Different variations of the CysDB format have been evaluated with four particular versions demonstrating the most promise with respect to binding and expression level. For each individual antibody, the heavy and light chain variable domains associate in different ways. For this reason, the use of different linker lengths allows for conformational flexibility and range-of-motion to ensure formation of the disulfide bonds. In some embodiments, the two linker length variants have either a 5 amino acid linker or an 8 amino acid linker. Each linker length variant may be developed using both orientations (VL-linker-VH-Cys tail and VH-linker-VL-Cys tail) to ensure the proper folding and stability is achieved. According to some embodiments, four CysDB variants that may be used in methods described herein have been constructed: VH5VL, VH8VL, VL5VH, and VL8VH (see Figures 6-9). Although each of the CysDB variants has been successfully expressed, results may vary depending on the parental antibody used. Producing and testing the expression and binding of all four variants ensures identification of an optimal format for protein

production for each new CysDB. Evaluating the set of variants is important to ensure that a high-quality, stable protein is produced where the disulfide bridge is available. Therefore, engineering a CysDB actually involves using two distinct linker lengths, not one – as in the minibody, as well as both orientations of the variable regions, VH/VL and VL/VH.

**[0055]** In some embodiments, a mammalian cell line (e.g., CHO-K1 cell line) may be used as an expression system to produce the minibodies, cys-diabodies or other antibody fragments described herein. However, because the minibodies, cys-diabodies and other antibody fragments described herein are non-glycosylated, the cell line or expression system, a mammalian expression system is not required, as such post-translational modifications are not needed. As such, a wide variety of mammalian and non-mammalian expression systems may be used to produce the PSMA antibody fragments (e.g., anti-PSMA minibodies and cys-diabodies) according to the embodiments of the disclosure including, but not limited to mammalian expression systems (e.g., CHO-K1 cells), bacterial expression systems (e.g., *E. Coli*, *B. subtilis*) yeast expression systems (e.g., *Pichia*, *S. cerevisiae*) or any other known expression system.

**[0056]** As described in detail in the Examples below, four minibody variants that differ in the svFv region were made and expressed in CHO-K1 cells. Specific binding to PSMA was demonstrated by ELISA and flow cytometry. One of the variants with high expression and PSMA binding (J591 HC VHVL) was selected for protein production, purification and further evaluation. Protein production of the J591 HC VHVL minibody was successfully scaled-up to produce sufficient amounts for the internalization and microPET imaging experiments described below.

**[0057]** Confocal microscopy studies of the J591 minibody showed increased intracellular staining in CWR22rv1 and LNCaP cells over time, similar to that of the intact huJ591 mAb, suggesting that the J591 minibodies undergo rapid internalization. To further evaluate internalization of the J591 minibody, two radiolabeling strategies were employed: radioiodination with I-131 and DOTA conjugation for radiometal labeling with In-111. The <sup>111</sup>In-DOTA J591 minibody showed a 260% increase in cell-associated

radioactivity over a 3 hour time period. In contrast, initial cell binding of  $^{131}\text{I}$ - J591 minibody was followed by a significant loss to 80% of the initial activity.

**[0058]** The J591 minibody is rapidly internalized upon binding to PSMA+ cell lines CWR22rv1 and LNCaP. For  $^{131}\text{I}$ -labeled J591 minibody, the total cell-associated radioactivity decreased over time suggesting loss of label likely attributed to dehalogenation and/or rapid metabolism and release from the cells of the  $^{131}\text{I}$ -J591 minibody. In contrast, the total cell-associated radioactivity of the  $^{111}\text{In}$ -DOTA- J591 minibody increased significantly over time (~2.5 fold) which is consistent with the residualizing label being trapped in the lysosomes. Based on the persistence of total cell-associated radioactivity over time, the residualizing  $^{111}\text{In}$ -DOTA radiolabeling strategy appeared to be the appropriate approach for *in vivo* imaging of the internalizing PSMA antigen.

#### **Anti-PSMA derivatives and conjugates**

**[0059]** In some embodiments, the PSMA antibodies or functional antibody fragments may include antibody derivatives that are modified. For example, the antibody derivatives include, but are not limited to, antibodies that have been modified by glycosylation, acetylation, pegylation, phosphorylation, amidation, derivatization by known protecting/blocking groups, proteolytic cleavage, and linkage to a cellular ligand or other protein. Any of numerous chemical modifications may be carried out by known techniques, including, but not limited to, specific chemical cleavage, acetylation, glycosylation and metabolic synthesis of tunicamycin. Additionally, the derivative may contain one or more non-natural amino acids.

**[0060]** In other embodiments, the PSMA antibody or functional antibody fragment may be conjugated to another substance to form an anti-PSMA conjugate. The anti-PSMA conjugates described herein can be prepared by known methods of linking antibodies with lipids, carbohydrates, protein or other atoms and molecules. In one aspect, the anti-PSMA conjugate is formed by site-specific conjugation using a suitable linkage or bond. Site-specific conjugation is more likely to preserve the binding activity of an antibody or functional antibody fragment. The substance may be conjugated or

attached at the hinge region of a reduced antibody component or antibody fragment via disulfide bond formation. For example, introduction of cysteine residues at the C-terminus of an scFv fragment, such as those introduced in the cys-diabodies described above, allows site-specific thiol-reactive coupling at a site away from the antigen binding site to a wide variety of agents. Alternatively, other linkages or bonds used to form the anti-PSMA conjugate may include, but is not limited to, a covalent bond, a non-covalent bond, a sulfide linkage, a hydrazone linkage, a hydrazine linkage, an ester linkage, an amido linkage, and amino linkage, an imino linkage, a thiosemicarbazone linkage, a semicarbazone linkage, an oxime linkage and a carbon-carbon linkage.

**[0061]** In one embodiment, the anti-PSMA conjugate may include a PSMA antibody or functional PSMA antibody fragment conjugated to a diagnostic agent. A "diagnostic agent" is an atom, molecule, or compound that is useful in diagnosing, detecting or visualizing a disease. According to the embodiments described herein, diagnostic agents may include, but are not limited to, radioactive substances (e.g., radioisotopes, radionuclides, radiolabels or radiotracers), dyes, contrast agents, fluorescent compounds or molecules, bioluminescent compounds or molecules, enzymes and enhancing agents (e.g., paramagnetic ions). In addition, it should be noted that some nanoparticles, for example quantum dots and metal nanoparticles (described below) may also be suitable for use as a detection agent.

**[0062]** Radioactive substances that may be used as diagnostic agents in accordance with the embodiments of the disclosure include, but are not limited to,  $^{18}\text{F}$ ,  $^{32}\text{P}$ ,  $^{33}\text{P}$ ,  $^{45}\text{Ti}$ ,  $^{47}\text{Sc}$ ,  $^{52}\text{Fe}$ ,  $^{59}\text{Fe}$ ,  $^{62}\text{Cu}$ ,  $^{64}\text{Cu}$ ,  $^{67}\text{Cu}$ ,  $^{67}\text{Ga}$ ,  $^{68}\text{Ga}$ ,  $^{75}\text{Sc}$ ,  $^{77}\text{As}$ ,  $^{86}\text{Y}$ ,  $^{90}\text{Y}$ ,  $^{89}\text{Sr}$ ,  $^{89}\text{Zr}$ ,  $^{94}\text{Tc}$ ,  $^{94}\text{Tc}$ ,  $^{99\text{m}}\text{Tc}$ ,  $^{99}\text{Mo}$ ,  $^{105}\text{Pd}$ ,  $^{105}\text{Rh}$ ,  $^{111}\text{Ag}$ ,  $^{111}\text{In}$ ,  $^{123}\text{I}$ ,  $^{124}\text{I}$ ,  $^{125}\text{I}$ ,  $^{131}\text{I}$ ,  $^{142}\text{Pr}$ ,  $^{143}\text{Pr}$ ,  $^{149}\text{Pm}$ ,  $^{153}\text{Sm}$ ,  $^{154-158}\text{Gd}$ ,  $^{161}\text{Tb}$ ,  $^{166}\text{Dy}$ ,  $^{166}\text{Ho}$ ,  $^{169}\text{Er}$ ,  $^{175}\text{Lu}$ ,  $^{177}\text{Lu}$ ,  $^{186}\text{Re}$ ,  $^{188}\text{Re}$ ,  $^{189}\text{Re}$ ,  $^{194}\text{Ir}$ ,  $^{198}\text{Au}$ ,  $^{199}\text{Au}$ ,  $^{211}\text{At}$ ,  $^{211}\text{Pb}$ ,  $^{212}\text{Bi}$ ,  $^{212}\text{Pb}$ ,  $^{213}\text{Bi}$ ,  $^{223}\text{Ra}$  and  $^{225}\text{Ac}$ . Paramagnetic ions that may be used as diagnostic agents in accordance with the embodiments of the disclosure include, but are not limited to, ions of transition and lanthanide metals (e.g. metals having atomic numbers of 6 to 9, 21-29, 42, 43, 44, or 57-71). These metals include ions of Cr, V, Mn, Fe, Co, Ni, Cu, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb and Lu.

**[0063]** When the diagnostic agent is a radioactive metal or paramagnetic ion, the agent may be reacted with a reagent having a long tail with one or more chelating groups attached to the long tail for binding these ions. The long tail may be a polymer such as a polylysine, polysaccharide, or other derivatized or derivatizable chain having pendant groups to which may be bound to a chelating group for binding the ions. Examples of chelating groups that may be used according to the disclosure include, but are not limited to, ethylenediaminetetraacetic acid (EDTA), diethylenetriaminepentaacetic acid (DTPA), DOTA, NOTA, NETA, porphyrins, polyamines, crown ethers, bis-thiosemicarbazones, polyoximes, and like groups. The chelate is normally linked to the PSMA antibody or functional antibody fragment by a group which enables formation of a bond to the molecule with minimal loss of immunoreactivity and minimal aggregation and/or internal cross-linking. The same chelates, when complexed with non-radioactive metals, such as manganese, iron and gadolinium are useful for MRI, when used along with the antibodies and carriers described herein. Macrocyclic chelates such as NOTA, DOTA, and TETA are of use with a variety of metals and radiometals including, but not limited to, radionuclides of gallium, yttrium and copper, respectively. Other ring-type chelates such as macrocyclic polyethers, which are of interest for stably binding nuclides, such as  $^{223}\text{Ra}$  for RAIT may be used. In certain embodiments, chelating moieties may be used to attach a PET imaging agent, such as an  $\text{Al-}^{18}\text{F}$  complex, to a targeting molecule for use in PET analysis.

**[0064]** Contrast agents that may be used as diagnostic agents in accordance with the embodiments of the disclosure include, but are not limited to, barium, diatrizoate, ethiodized oil, gallium citrate, iocarmic acid, iocetamic acid, iodamide, iodipamide, iodoxamic acid, iogulamide, iohexyl, iopamidol, iopanoic acid, ioprocemic acid, iocefamic acid, ioserlic acid, iosulamide meglumine, iosemetic acid, iotasul, iotetric acid, iothalamate, iotroxic acid, ioxaglic acid, ioxotrizoic acid, ipodate, meglumine, metrizamide, metrizoate, propyl iodone, thallous chloride, or combinations thereof.

**[0065]** Bioluminescent and fluorescent compounds or molecules and dyes that may be used as diagnostic agents in accordance with the embodiments of the

disclosure include, but are not limited to, fluorescein, fluorescein isothiocyanate (FITC), Oregon Green.TM., rhodamine, Texas red, tetra-rhodamine isothiocyanate (TRITC), Cy3, Cy5, etc.), fluorescent markers (e.g., green fluorescent protein (GFP), phycoerythrin, etc.), autoquenched fluorescent compounds that are activated by tumor-associated proteases, enzymes (e.g., luciferase, horseradish peroxidase, alkaline phosphatase, etc.), nanoparticles, biotin, digoxigenin or combination thereof.

**[0066]** Enzymes that may be used as diagnostic agents in accordance with the embodiments of the disclosure include, but are not limited to, horseradish peroxidase, alkaline phosphatase, acid phosphatase, glucose oxidase,  $\beta$ -galactosidase,  $\beta$ -glucuronidase or  $\beta$ -lactamase. Such enzymes may be used in combination with a chromogen, a fluorogenic compound or a luminogenic compound to generate a detectable signal.

**[0067]** In another embodiment, the anti-PSMA conjugate may include a PSMA antibody or functional PSMA antibody fragment conjugated to a therapeutic agent. A "therapeutic agent" as used herein is an atom, molecule, or compound that is useful in the treatment of cancer or other conditions associated with PSMA. Examples of therapeutic agents include, but are not limited to, drugs, chemotherapeutic agents, therapeutic antibodies and antibody fragments, toxins, radioisotopes, enzymes (e.g., enzymes to cleave prodrugs to a cytotoxic agent at the site of the tumor), nucleases, hormones, immunomodulators, antisense oligonucleotides, chelators, boron compounds, photoactive agents and dyes.

**[0068]** Chemotherapeutic agents are often cytotoxic or cytostatic in nature and may include alkylating agents, antimetabolites, anti-tumor antibiotics, topoisomerase inhibitors, mitotic inhibitors hormone therapy, targeted therapeutics and immunotherapeutics. In some embodiments the chemotherapeutic agents that may be used as diagnostic agents in accordance with the embodiments of the disclosure include, but are not limited to, 13-cis-Retinoic Acid, 2-Chlorodeoxyadenosine, 5-Azacytidine, 5-Fluorouracil, 6-Mercaptopurine, 6-Thioguanine, actinomycin-D, adriamycin, aldesleukin, alemtuzumab, alitretinoin, all-transretinoic acid, alpha

interferon, altretamine, amethopterin, amifostine, anagrelide, anastrozole, arabinosylcytosine, arsenic trioxide, amsacrine, aminocamptothecin, aminoglutethimide, asparaginase, azacytidine, bacillus calmette-guerin (BCG), bendamustine, bevacizumab, bexarotene, bicalutamide, bortezomib, bleomycin, busulfan, calcium leucovorin, citrovorum factor, capecitabine, canertinib, carboplatin, carmustine, cetuximab, chlorambucil, cisplatin, cladribine, cortisone, cyclophosphamide, cytarabine, darbepoetin alfa, dasatinib, daunomycin, decitabine, denileukin diftitox, dexamethasone, dexasone, dexrazoxane, dactinomycin, daunorubicin, decarbazine, docetaxel, doxorubicin, doxifluridine, eniluracil, epirubicin, epoetin alfa, erlotinib, everolimus, exemestane, estramustine, etoposide, filgrastim, fluoxymesterone, fulvestrant, flavopiridol, floxuridine, fludarabine, fluorouracil, flutamide, gefitinib, gemcitabine, gemtuzumab ozogamicin, goserelin, granulocyte - colony stimulating factor, granulocyte macrophage-colony stimulating factor, hexamethylmelamine, hydrocortisone hydroxyurea, ibritumomab, interferon alpha, interleukin – 2, interleukin-11, isotretinoin, ixabepilone, idarubicin, imatinib mesylate, ifosfamide, irinotecan, lapatinib, lenalidomide, letrozole, leucovorin, leuprolide, liposomal Ara-C, lomustine, mechlorethamine, megestrol, melphalan, mercaptopurine, mesna, methotrexate, methylprednisolone, mitomycin C, mitotane, mitoxantrone, nelarabine, nilutamide, octreotide, oprelvekin, oxaliplatin, paclitaxel, pamidronate, pemetrexed, panitumumab, PEG Interferon, pegaspargase, pegfilgrastim, PEG-L-asparaginase, pentostatin, plicamycin, prednisolone, prednisone, procarbazine, raloxifene, rituximab, romiplostim, ralitrexed, sapacitabine, sargramostim, satraplatin, sorafenib, sunitinib, semustine, streptozocin, tamoxifen, tegafur, tegafur-uracil, temsirolimus, temozolamide, teniposide, thalidomide, thioguanine, thiotepa, topotecan, toremifene, tositumomab, trastuzumab, tretinoin, trinitrexate, alrubicin, vincristine, vinblastine, vindestine, vinorelbine, vorinostat, or zoledronic acid.

**[0069]** Therapeutic antibodies and functional fragments thereof, that may be used as diagnostic agents in accordance with the embodiments of the disclosure include, but are not limited to, alemtuzumab, bevacizumab, cetuximab, edrecolomab, gemtuzumab, ibritumomab tiuxetan, panitumumab, rituximab, tositumomab, and trastuzumab

**[0070]** Toxins that may be used as diagnostic agents in accordance with the embodiments of the disclosure include, but are not limited to, ricin, abrin, ribonuclease (RNase), DNase I, Staphylococcal enterotoxin-A, pokeweed antiviral protein, gelonin, diphtheria toxin, Pseudomonas exotoxin, and Pseudomonas endotoxin.

**[0071]** Radioisotopes that may be used as diagnostic agents in accordance with the embodiments of the disclosure include, but are not limited to,  $^{32}\text{P}$ ,  $^{89}\text{Sr}$ ,  $^{90}\text{Y}$ ,  $^{99\text{m}}\text{Tc}$ ,  $^{99}\text{Mo}$ ,  $^{131}\text{I}$ ,  $^{153}\text{Sm}$ ,  $^{177}\text{Lu}$ ,  $^{186}\text{Re}$ ,  $^{213}\text{Bi}$ ,  $^{223}\text{Ra}$  and  $^{225}\text{Ac}$ .

**[0072]** In another embodiment, the anti-PSMA conjugate may include a PSMA antibody or functional PSMA antibody fragment conjugated to a nanoparticle. The term "nanoparticle" refers to a microscopic particle whose size is measured in nanometers, e.g., a particle with at least one dimension less than about 100 nm. Nanoparticles are particularly useful as detectable substances because they are small enough to scatter visible light rather than absorb it. For example, gold nanoparticles possess significant visible light extinction properties and appear deep red to black in solution. As a result, compositions comprising PSCA-specific antibody or fragments conjugated to nanoparticles can be used for the *in vivo* imaging of tumors or cancerous cells in a subject. At the small end of the size range, nanoparticles are often referred to as clusters. Metal, dielectric, and semiconductor nanoparticles have been formed, as well as hybrid structures (e.g. core-shell nanoparticles). Nanospheres, nanorods, and nanocups are just a few of the shapes that have been grown. Semiconductor quantum dots and nanocrystals are examples of additional types of nanoparticles. Such nanoscale particles, when conjugated to a PSMA antibody or functional antibody fragment, can be used as imaging agents for the *in vivo* detection of tumor cells as described above. Alternatively, nanoparticles can be used in therapeutic applications as drug carriers that, when conjugated to a PSCA-specific antibody or fragment of the present invention, deliver chemotherapeutic agents, hormonal therapeutic agents, radiotherapeutic agents, toxins, or any other cytotoxic or anti-cancer agent known in the art to cancerous cells that overexpress PSCA on the cell surface.

**[0073]** Any of the anti-PSMA conjugates described above may be further conjugated with one or more additional therapeutic agents, diagnostic agents, nanoparticles, carriers or a combination thereof. For example, a PSMA antibody or functional PSMA antibody fragment may be radiolabeled with  $^{131}\text{I}$  and conjugated to a lipid carrier, such that the anti-PSMA-lipid conjugate forms a micelle. The micelle may incorporate one or more therapeutic or diagnostic agents. Alternatively, in addition to the carrier, the PSMA antibody or functional PSMA antibody fragment may be conjugated to  $^{131}\text{I}$  (e.g., at a tyrosine residue) and a drug (e.g., at the epsilon amino group of a lysine residue), and the carrier may incorporate an additional therapeutic or diagnostic agent.

#### **Methods for diagnosing, staging and monitoring cancer**

**[0074]** The PSMA antibody, functional PSMA antibody fragment or anti-PSMA conjugate may be used to target a PSMA positive cell, such as cancer cells that overexpress PSMA. Therefore, methods for diagnosing, detecting, visualizing, monitoring or treating a cancer or other condition associated with PSMA expression may include administering the PSMA antibody, functional PSMA antibody fragment or anti-PSMA conjugate to a subject having or suspected of having a cancer or other condition associated with PSMA expression. As used herein, the term "subject" refers to any animal (e.g., a mammal), including but not limited to humans, non-human primates, rodents, dogs, pigs, and the like.

**[0075]** Cancers that are associated with PSMA expression may include those having cancer tumor tissue that overexpresses PSMA (e.g., prostate cancer) or those having solid tumor neovasculature that overexpresses PSMA (e.g., prostate cancer, lung cancer, colon (or colorectal) cancer, breast cancer, renal cancer, liver cancer, bladder cancer and pancreatic cancer as well as sarcomas and melanoma). Most solid tumor neovasculature expresses PSMA, making PSMA a neovasculature biomarker. Thus, in addition to cancer cells that expresses PSMA, a cancer that is associated with PSMA expression may include any cancer tissue with neovasculature including, but not limited to, carcinomas such as prostate cancer, lung cancer, colon (or colorectal)

cancer, breast cancer, renal cancer, liver cancer, bladder cancer and pancreatic cancer as well as sarcomas and melanoma.

**[0076]** In one embodiment, a method for diagnosing, detecting, visualizing or monitoring a cancer associated with PSMA expression includes administering a diagnostic anti-PSMA conjugate to a subject having or suspected of having a cancer. . The diagnostic anti-PSMA conjugate includes a PSMA antibody or a functional PSMA antibody fragment conjugated to one or more diagnostic agents as described above. In one embodiment, the PSMA antibody, or a functional PSMA antibody fragment is a minibody or a CysDB, derived from a J591 antibody such as those J591 minibodies and J591 CysDBs described herein. The diagnostic anti-PSMA conjugate may be conjugated to or associated with one or more additional substances described herein, such as a therapeutic anti-PSMA conjugate (as described below), unconjugated therapeutic agents, contrast solutions, carrier lipids or nanoparticles.

**[0077]** The diagnostic anti-PSMA conjugate used in the method described above is suitable for *in vivo* or *in vitro* detection or visualization methods. In one embodiment, an *in vitro* diagnostic or prognostic assay will be performed to determine the expression level of PSMA in a tissue sample taken from a subject having or suspected of having a cancer associated with PSMA as compared to a normal (i.e., non cancerous) or control tissue sample (i.e., known cancerous or benign tissue sample). Various assays for determining such expression levels are contemplated and include immunohistochemistry, fluorescent in situ hybridization (FISH) and shed antigen assays, southern blotting, or PCR techniques.

**[0078]** In another embodiment, the diagnostic anti-PSMA conjugate may be used with an *in vivo* imaging modality to visualize the target cells within the topography of the subject's body. According to the method described herein, determining that the subject has a cancer associated with PSMA expression is accomplished by visualizing the labeled minibody or CysDB, wherein the visualized labeled minibody or CysDB localizes to a tumor site. In addition to diagnosing a cancer associated with PSMA

expression, the PSMA minibody may also be used to stage, and monitor cancer progression according to method that are similar to those described above.

**[0079]** Suitable methods of *in vivo* imaging that may be used in accordance with the methods described herein include, but are not limited to, magnetic resonance imaging (MRI), positron emission tomography (PET) or microPET, computed tomography (CT), PET/CT combination imager, cooled charged coupled device (CCD), camera optical imaging, optical imaging (e.g., bioluminescent optical imaging, fluorescent optical imaging, or absorption of reflectance) and single photon emission computed tomography (SPECT),

**[0080]** As described in the examples below, a minibody or CysDB as described herein that is labeled with an appropriate radioisotope (e.g., residualizing  $^{124}\text{I}$ ,  $^{64}\text{Cu}$  - DOTA or  $^{89}\text{Zr}$ -DOTA), may be used as a clinical imaging agent to target PSMA *in vivo* according to the methods described herein. These J591 minibodies and CysDBs may also be developed as a potential single photon emission computed tomography (SPECT) imaging agent according to embodiments described herein. The J591 minibody may be used as a SPECT imaging agent by changing the radiolabel, for example,  $^{111}\text{In}$ -DOTA-J591.

**[0081]** The J591 minibodies described herein were evaluated for tumor targeting by small-animal PET (microPET) and biodistribution experiments following radiolabeling with the positron emitters I-124 ( $t_{1/2}$ = 4.2d) and Cu-64 ( $t_{1/2}$ = 12.7h) to compare retention of cell-associated radioactivity *in vivo*.

**[0082]** Both  $^{124}\text{I}$  and  $^{64}\text{Cu}$ -DOTA labelled J591 minibodies rapidly targeted the CWR22rv1 tumor with high uptake and specificity. Serial imaging of mice carrying PSMA positive CWR22rv1 and negative PC-3 xenografts resulted in high contrast images and excellent tumor uptakes with both labels. At 19 hours p.i.,  $8.2(\pm 1.2)$  %ID/g and  $8.8(\pm 2.0)$  %ID/g were achieved with  $^{64}\text{Cu}$ -DOTA- and  $^{124}\text{I}$ -J591 minibodies, respectively. At 43 hours post injection (p.i.), tumor uptake increased to  $13.3(\pm 8.3)$  %ID/g with the  $^{64}\text{Cu}$ -DOTA-J591 minibodies, which declined to  $3.25(\pm 0.9)$  %ID/g with the  $^{124}\text{I}$ - J591 minibodies. Positive to negative tumor ratios were 3.1 and 4.9 at 19 hours

and 5.4 and 7.3 at 43 hours for  $^{64}\text{Cu}$ -DOTA- and  $^{124}\text{I}$ -J591 minibodies, respectively. Persistent high liver uptake [ $21.4(\pm 3.1)$  %ID/g at 19hr and  $14.4(\pm 2.1)$  %ID/g at 43hr] was seen with  $^{64}\text{Cu}$ -DOTA-J591 minibodies, whereas the  $^{124}\text{I}$ -J591 minibodies exhibited rapid background clearance resulting in higher contrast images. The similar tumor uptakes of both radiolabeled minibodies at 19 hours were unexpected, and suggestive of slower *in vivo* internalization. Thus, the J591 minibodies radiolabeled with I-124 is an efficient tracer for detecting PSMA positive cells.

### Methods for treating cancer

**[0083]** In some embodiments, methods for treating cancer or other condition associated with overexpression of PSMA are provided. Such methods include administering to a subject a therapeutically effective amount of a pharmaceutical composition that includes a PSMA antibody, or a functional PSMA antibody fragment as described above. In one embodiment, the PSMA antibody, or a functional PSMA antibody fragment is a minibody or a CysDB, derived from a J591 antibody such as those J591 minibodies and J591 CysDBs described herein.

**[0084]** "Treating" or "treatment" of a condition may refer to preventing the condition, slowing the onset or rate of development of the condition, reducing the risk of developing the condition, preventing or delaying the development of symptoms associated with the condition, reducing or ending symptoms associated with the condition, generating a complete or partial regression of the condition, or some combination thereof.

**[0085]** A "therapeutically effective amount" or a "therapeutically effective dose" is an amount of a compound that produces a desired therapeutic effect in a subject, such as preventing or treating a target condition or alleviating symptoms associated with the condition. The precise therapeutically effective amount is an amount of the composition that will yield the most effective results in terms of efficacy of treatment in a given subject. This amount will vary depending upon a variety of factors, including but not limited to the characteristics of the therapeutic compound (including activity, pharmacokinetics, pharmacodynamics, and bioavailability), the physiological condition

of the subject (including age, sex, disease type and stage, general physical condition, responsiveness to a given dosage, and type of medication), the nature of the pharmaceutically acceptable carrier or carriers in the formulation, and the route of administration. One skilled in the clinical and pharmacological arts will be able to determine a therapeutically effective amount through routine experimentation, namely by monitoring a subject's response to administration of a compound and adjusting the dosage accordingly. For additional guidance, see Remington: The Science and Practice of Pharmacy 21<sup>st</sup> Edition, Univ. of Sciences in Philadelphia (USIP), Lippincott Williams & Wilkins, Philadelphia, PA, 2005.

**[0086]** In one embodiment, the pharmaceutical composition may include a therapeutic anti-PSMA conjugate, wherein the conjugate includes a PSMA antibody or a functional PSMA antibody fragment conjugated to one or more therapeutic agent as described above. In one embodiment, the PSMA antibody, or a functional PSMA antibody fragment is a minibody or a CysDB, derived from a J591 antibody such as those J591 minibodies and J591 CysDBs described herein. For example, the J591 minibodies or cys-diabodies described herein may be used in a radioimmunotherapy approach, wherein one or more of the 3B J591 minibodies is radiolabeled with an appropriate beta-emitting radiolabel such as Yttrium-90. The radiolabeled 3B J591 minibody or minibodies may be used to deliver cell damage and death to local cancerous tissue that expresses PSMA. Further, the use of radiolabeled J591 minibodies and cys-diabodies would likely exhibit improved tumor penetration as compared to radiolabeled full-length parental huJ591 antibody.

**[0087]** The therapeutic anti-PSMA conjugate may be conjugated to or associated with one or more additional substances described herein, such as diagnostic anti-PSMA conjugates (described above), unconjugated diagnostic agents, contrast solutions, carrier lipids or nanoparticles.

**[0088]** In some embodiments, the pharmaceutical composition may also include a pharmaceutically acceptable carrier. A pharmaceutically acceptable carrier may be a pharmaceutically acceptable material, composition, or vehicle that is involved in carrying

or transporting a compound of interest from one tissue, organ, or portion of the body to another tissue, organ, or portion of the body. For example, the carrier may be a liquid or solid filler, diluent, excipient, solvent, or encapsulating material, or some combination thereof. Each component of the carrier must be "pharmaceutically acceptable" in that it must be compatible with the other ingredients of the formulation. It also must be suitable for contact with any tissue, organ, or portion of the body that it may encounter, meaning that it must not carry a risk of toxicity, irritation, allergic response, immunogenicity, or any other complication that excessively outweighs its therapeutic benefits.

**[0089]** The pharmaceutical compositions described herein may be administered by any suitable route of administration. A route of administration may refer to any administration pathway known in the art, including but not limited to aerosol, enteral, nasal, ophthalmic, oral, parenteral, rectal, transdermal (e.g., topical cream or ointment, patch), or vaginal. "Transdermal" administration may be accomplished using a topical cream or ointment or by means of a transdermal patch. "Parenteral" refers to a route of administration that is generally associated with injection, including infraorbital, infusion, intraarterial, intracapsular, intracardiac, intradermal, intramuscular, intraperitoneal, intrapulmonary, intraspinal, intrasternal, intrathecal, intrauterine, intravenous, subarachnoid, subcapsular, subcutaneous, transmucosal, or transtracheal.

The following examples are intended to illustrate various embodiments of the invention. As such, the specific embodiments discussed are not to be construed as limitations on the scope of the invention. It will be apparent to one skilled in the art that various equivalents, changes, and modifications may be made without departing from the scope of invention, and it is understood that such equivalent embodiments are to be included herein.

### **Example 1: Generation of the J591 Minibodies**

**[0090]** *J591 minibody construct.* Third generation J591 minibodies are engineered antibody fragments that incorporate modified variable regions of the full-

length parental huJ591 antibody. The minibody format is a homodimer wherein each monomer is a single-chain variable fragment (scFv) linked to a human IgG1 CH3 domain (Figure 1A). The scFv can have a VHVL or a VLVH orientation. As shown in Figure 1B, the J591 minibody expression construct for a an scFv having a VHVL orientation has a variable heavy (VH) domain that is linked to a variable light (VL) region by an 18 amino acid linker (L) sequence. In a VLVH orientation, the VL and VH would be switched in Figure 1B such that the VL region is upstream of the VH domain.

**[0092]** Four J591 minibody sequences were synthesized for use in the expression studies described below: The minibody sequences that were constructed as follows:

- 1) J591 Human Composite (HC) with a VHVL orientation (J591 HC VHVL; SEQ ID NO:1);
- 2) J591 Human Composite (HC) with a VLVH orientation (J591 HC VLVH);
- 3) J591 with the 2 Proline substitutions (2P) with a VHVL orientation (J591 2P VHVL; SEQ ID NO:2); and
- 4) J591 with the 2 Proline substitutions (2P) with a VLVH orientation (J591 2P VLVH).

**[0093]** Figure 3 shows the sequence of the J591 HC VHVL minibody (SEQ ID NO:1) and Figure 4 shows the sequence of the J591 2P VHVL minibody (SEQ ID NO:2). The 18 amino acid linker (L) has a specific sequence of GlySer-rich residues (see Figure 1, for sequence see Figures 3 and 4). The scFv is tethered to the human IgG1 CH3 domain by an artificial hinge sequence wherein the first 15 residues are that of the human IgG1 hinge followed by a 10 amino acid GlySer linker sequence (see Figure 1, for sequence see Figure 3 and 4). This specific hinge sequence has also been successfully incorporated into previous minibodies. The minibody (either VH-VL-CH3 or VL-VH-CH3 orientation) exists as a stable dimer due to the association between the CH3 domains as well as the formation of disulfide bonds within the hinge regions. To enable secretion of the minibody, a kappa light chain signal sequence leads the

expression construct and fused at the N-terminus of the variable heavy domain (see Figure 1B, for sequence see Figure 3 and 4).

**[0093]** A set of J591 minibodies were engineered by making amino acid substitutions in the parental huJ591 variable heavy and light domains. Sequence analysis of the full length parental huJ591 variable regions identified an unusually high number of conformationally restrictive Proline residues, which are recognized to decrease the flexibility of protein structure. A comparison of sequence alignment between the deimmunized J591 (SEQ ID NO:5; SEQ ID NO:19) and the original murine J591 (SEQ ID NO:4; SEQ ID NO:18) revealed that the deimmunization process introduced additional Proline residues (see Figure 2). After sequence and protein modeling analysis, two changes to the protein were made to improve the flexibility and folding ability. First, two Proline residues were changed in the variable light domain (P42Q and P100A) to the residues found in the murine sequence (see Figure 2, here forth referred to as 2P). Second, substitutions were calculated for both variable regions using Human Composite (HC) Antibody technology (Antitope) that deimmunizes the sequence by avoiding potential epitopes instead of destroying epitopes (see Figure 2, here forth referred to as HC).

**[0094]** *Expression of the J591 minibodies.* Expression vectors for each of the four minibody sequences above were generated. Each of the four minibody sequences was cloned into the pcDNA3.1/myc-His (-) Version A vector for mammalian expression (Invitrogen, Inc.) at the corresponding XbaI/HindIII sites. The pcDNA3.1 expression vector features a CMV promoter for mammalian expression and both mammalian (Neomycin) and bacterial (Ampicillin) selection markers (see Figure 10).

**[0095]** The four J591 minibody expression vectors were transiently transfected into CHO-K1 cells to validate expression of the J591 minibodies. The transfections were performed using the Lipofectamine™ reagent in a 6-well plate format. Following a 72 hour transfection, the supernatants were harvested and filtered to remove any cells.

**[0096]** To confirm the expression of the J591 minibodies by the CHO-K1 cells, Western blot analyses were performed using sample of supernatant taken from the

transient transfections. Supernatant from an empty vector transfection was included as a negative control, and supernatant from the transfection of a different minibody was used as a positive control. Transfection supernatants were run out by SDS-PAGE and transferred to PVDF membrane. The membrane was probed with an anti-human IgG (Fc-specific) antibody conjugated with Alkaline Phosphatase (AP) and developed by incubating with the AP substrate BCIP/NBT. Figure 11 is a representative blot of multiple experiments that confirmed the expression of the J591 minibodies. Under non-reducing conditions, the J591 minibodies run at the expected molecular weight of approximately 90kD (Figure 11). A minor band representing the monomeric form was also detected at approximately 40kD.

**[0098]** Quantitative ELISAs were performed to analyze J591 minibody expression from transient transfection. ELISA is a sandwich assay which uses a goat anti-human IgG (Fc specific) as the capture antibody and an AP-conjugated goat anti-human IgG (Fc specific) as the detection antibody. Purified protein for a previously produced minibody was used as a standard. J591 minibody supernatants were serially diluted to find dilution points which fit in the linear range of the standard curve. The program SoftMax Pro was used to interpolate the concentration of the unknowns according to the standard curve.

**[0099]** Supernatants from multiple transfections were assayed, and the averages are displayed in Figure 25. The J591 HC VHVL minibody exhibited the highest expression (6.7 ug/ml) of the third generation minibodies.

**[00100]** *Binding ability of the J591 minibodies.* To confirm the ability of the J591 minibodies to bind cellular PSMA, supernatant from the transient transfections described above were analyzed by flow cytometry. As illustrated in Figures 12A-12D, supernatants from the transient transfection for each of the J591 minibodies were tested for binding to LNCaP cells that are PSMA positive (PSMA+)(2) and compared to negative control cells that are PSMA negative. All supernatants were normalized to a concentration of 2.1 ug/ml of J591 minibody. Cells were subsequently stained with a secondary anti-human IgG (Fc specific)-PE conjugated antibody. Negative control cells

were stained with the secondary alone (1).  $1 \times 10^5$  cells/point and analysis was performed with 10,000 events/point.

**[00101]** Each of the cell populations stained with the J591 minibodies demonstrated a significant increase in signal relative to the negative control cells (see Figure 12). The J591 minibody supernatants did not significantly stain negative control PC3 cells (PSMA negative) (data not shown). All four minibodies exhibited comparable binding affinity to the LNCaP cells (see Figure 12).

### **Example 2: Stable cell line production**

**[00102]** Based on the expression and binding data described above, the J591 Human Composite VHVL (HC VHVL) minibody was selected as a lead candidate to move forward into larger scale (~low milligram quantity) protein production for subsequent *in vivo* imaging studies described below. Although the Examples described below are specific to the J591 HC VHVL minibody, however, it is noted that any of the J591 minibodies or cys-diabodies described herein may be purified and used in similar studies.

**[00103]** The J591 HC VHVL minibody was stably transfected into CHO-K1 cells using Neomycin as the selection marker. Following selection for high-expressing clones, a clone expressing the J591 minibody at approximately 36 mg/L (over a 4 day culture) was chosen for scale-up production.

**[00104]** *Protein Production Run.* To produce at least 10mg of final purified protein, the stable cell line was expanded to a 400ml production run (in 2% FBS media). Cells were seeded into eight T175 flasks, and the production run lasted for 7 days.

**[00105]** *Protein Purification.* At the end of the production run, the supernatant was harvested, spun down to remove any cells, and filtered using 0.2 um filter units. The J591 minibody was purified from the supernatant using Protein L affinity chromatography. After loading, the column was washed with PBS (pH= 7.2) and the minibody was eluted from the column using IgG Elution Buffer (Pierce, Thermo Scientific). Eluted fractions were immediately neutralized using 1M Tris buffer (pH=8).

The final elution fractions were concentrated and buffer exchanged into the final formulation of PBS (pH=7.2).

**[00106]** *Purified Protein Analysis.* After purification, the final concentration of J591 minibody protein was calculated using UV absorbance at 280A. The absorbance coefficient was 1.76 (absorbance Units at A280 per mg/ml). The final concentration of the protein was 1.06 mg/ml.

**[00107]** To analyze the purity of the J591 minibody, the protein was run under non-reducing and reducing conditions by SDS-PAGE. Under non-reducing conditions, the minibody was detected at approximately 85 kDa (Figure 13). A relatively minor smear was present under the 85kDa band which may represent a small amount of degradation. The minor band at approximately 40kDa represents the minibody monomer. Under reducing conditions, the minibody was detected as the monomeric form at around 40kDa (Figure 13).

**[00108]** To examine the purity of the assembled minibody complex, the protein was analyzed by size exclusion chromatography. 4 micrograms of the purified protein was analyzed by SEC (Figure 14). The major peak corresponds with minibody homodimer. The two minor peaks which eluted at earlier time points represent larger aggregate protein. Analysis of the area under the peaks showed that 85% of the protein product exists as the proper minibody homodimer vs 15% aggregate.

### **Example 3: J591 minibodies binds and is internalized by PSMA+ cells**

**[00109]** High-expressing stable cell pools were generated with Catalent's proprietary GPEx technology using lentiviral transductions of serum-free CHO-S cells. Using ion exchange chromatography, the J591 minibody was purified from the cell supernatant with sufficiently high purity for downstream experiments. High purity of the product was confirmed by SDS-PAGE and SEC analysis (>85% purity). The purified protein does not have any significant bioburden (0 cfu/ml) and relatively low endotoxin levels (between 8 and 16 EU/mg). The total yield from this production run batch was 65 mg of J591 minibody protein.

**[00110]**      *Functional ELISA.* To confirm the ability of the J591 minibody protein to bind purified PSMA, an indirect ELISA using purified recombinant PSMA was performed. A negative control minibody was included in the experiment. At the starting concentration of 2 µg/ml, the J591 minibody bound the recombinant PSMA at saturation (see Figure 15). Subsequent serial dilutions of the J591 minibody showed concentration-dependent binding (see Figure 15). As expected, the negative control minibody did not bind PSMA (see Figure 15).

**[00111]**      *Flow Cytometry.* Following successful binding to recombinant PSMA in the ELISA, the J591 minibody protein was tested for the ability to bind PSMA+ cells by flow cytometry. Full-length hJ591 antibody was included in the experiment as a positive control (data not shown) and the negative control minibody was also included. The PSMA+ cells in this experiment were the LNCaP and CWR22rv1 cells and the PSMA-cell line was the PC3. The J591 minibody clearly binds both the LNCaP (see Figure 16A) and the CWR22rv1 (see Figure 16C) compared to an equivalent concentration of the negative control minibody. LNCaP cells are known to have a higher expression of PSMA than the CWRs which may explain the higher PE signal of the cell population (see Figure 16, top row vs. bottom row). As anticipated, the J591 minibody did not significantly bind the PC3 cells (data not shown).

**[00112]**      Prior to this flow cytometry analysis, J591 minibody protein was conjugated with the bifunctional chelator 1,4,7,10-tetraazacyclododecane-N,N',N'',N'''-tetraacetic acid (DOTA) in preparation for downstream radiometal labeling. Conjugation was performed using the water-soluble N-hydroxysuccinimide method (Lewis et al 2001). Following DOTA conjugation, the protein conjugate was dialyzed to change buffer and remove excess DOTA.

**[00113]**      To verify binding ability after conjugation, the J591-DOTA minibody was tested for binding to PSMA by flow cytometry. Compared to the unconjugated J591 minibody, the J591-DOTA minibody exhibited a slight decrease in immunoreactivity as shown in the slight shift in the PE signal of the cell population (see Figure 16B and 16D). Excessive conjugation of bifunctional chelators to antibodies has been known to

be a cause for decrease in immunoreactivity (Kukis et al 1995). Conjugation conditions can be optimized to prevent excessive conjugation and the resulting loss of binding. However, the slight shift in binding for the J591-DOTA minibody was considered acceptable and the protein moved forward into radiolabeling.

**[00113]**      *Internalization of unlabeled minibody.* Internalization of the J591 minibody into PSMA+ cells was examined using immunofluorescence confocal microscopy. The two PSMA+ cell lines used in this experiment, the LNCaP and CWR22rv1 cell lines, have been previously used in cell-binding studies and also served in the subsequent radiolabeled internalization study. PC3 cells were used as the PSMA- negative control cell line. Full-length, parental J591 antibody was included in the experiment as a positive control. A negative control minibody was also included to further demonstrate the specificity of the J591 minibody uptake in PSMA+ cells.

**[00114]**      Since previous internalization studies with the original full-length J591 antibody on LNCaP cells showed strong internalization by 180 minutes (Liu et al 1998), cells were stained at  $t = 0$  and  $t = 180$  minutes after primary antibody incubation to measure internalization. Localization of the antibody and minibody were detected by a secondary anti-human IgG antibody conjugated with the Alexa 488 fluorophore. Cells were counterstained with DAPI for staining of the nucleus.

**[00115]**      The J591 full-length antibody showed very sharp and distinct staining of the plasma membrane at  $t=0$  (see Figure 17). After incubating 180 minutes at 37C, the J591 full-length antibody internalized into the LNCaP cells as shown by the dispersion of the of the Alexa™ 488 staining throughout the cell. The J591 minibody also showed distinct plasma membrane staining at  $t=0$  and strong internalization by  $t=180$  minutes (Figure 17). Staining of the J591 minibody at  $t=0$  was notably less distinct than the J591 full-length, perhaps suggesting a more rapid internalization for the smaller-sized minibody within LNCaP cells. The negative control minibody could not bind the LNCaP cells at  $t=0$ . The J591 full-length antibody and minibody could not bind the PSMA- PC3 cells (data not shown).

**[00117]** Internalization of the full-length J591 antibody into CWR22rv1 cells showed very similar staining pattern as seen for the LNCaP cells. Staining was very sharp and distinct on the plasma membrane at t=0 and became very dispersed by t=180 minutes (see Figure 18). The J591 minibody was also internalized in the CWR22rv1. Staining at t=0 was distinctively plasma membrane and became much more dispersed by t=180 minutes (Figure 18). As expected, the negative control minibody did not bind the CWR22rv1 cells (Figure 18).

#### **Example 4: Radiolabeled PSMA-specific minibodies**

**[00118]** *Radiolabeling J591 minibody with Iodine-131.* Purified J591 minibody protein (50µg) was radiolabeled with approximately 50µCi of <sup>131</sup>I using the Iodogen method from Pierce Thermo Scientific (as described in Olafsen et al 2006). This reagent enables the chemical oxidation reaction to attach <sup>131</sup>I to available Tyrosine residues of the J591 minibody. Table 2 is a summary of the J591 minibody radiolabeling results, including radiolabeling efficiency, percentage of bound radioactivity after purification, and specific activity. The radiolabeling efficiency was determined to be approximately 51% using instant thin layer chromatography (ITLC) to measure the percentage of radioactivity bound to the protein versus unbound. (see Table 2 below). The specific activity was determined to be 0.46 µCi/µg by measuring the total activity of the radiolabeled protein using a dose calibrator and calculating the specific activity based on the labeling efficiency (Table 2). To remove excess unbound <sup>131</sup>I, the radiolabeled protein was further purified using spin columns. The percentage of radioactivity bound to the J591 minibody following purification was dramatically increased to approximately 96% following purification (Table 2).

**[00119]** *DOTA-conjugating and radiometal labeling the J591 with Indium-111.* J591 minibody, previously conjugated with the bifunctional metal chelator DOTA, was radioabeled with <sup>111</sup>In. 100µg of the DOTA-J591 minibody was incubated with 200 µCi <sup>111</sup>In-chloride in 0.1M metal-free ammonium acetate (pH 6.0) at 43C for 50 minutes. The reaction was stopped by the addition of 10mM DTPA to a final concentration of 1mM. Radiolabeling efficiency was determined to be approximately 60% and the

specific activity was 1.1  $\mu\text{Ci}/\mu\text{g}$  (see Table 2). The radiolabeled protein was further purified to remove excess unbound  $^{111}\text{In}$  using spin columns. Similar to the  $^{131}\text{I}$ -J591 minibody, the percentage of radioactivity bound to the J591 minibody following purification was dramatically increased to approximately 94% (Table 2).

Table 2. Radiolabeling of the J591 Minibody with  $^{131}\text{I}$  and  $^{111}\text{In}$ .

|                         | Radiolabeling Efficiency (%) | % Bound Radioactivity Post-Purification | Specific Activity ( $\mu\text{Ci}/\mu\text{g}$ ) |
|-------------------------|------------------------------|-----------------------------------------|--------------------------------------------------|
| $^{131}\text{I}$        | 51%                          | 96.2%                                   | 0.46                                             |
| $^{111}\text{In}$ -DOTA | 60%                          | 94.2%                                   | 1.1                                              |

**[00120]** *Internalization and retention of radiolabeled J591 minibody.* The  $^{131}\text{I}$ -labeled and  $^{111}\text{In}$ -DOTA labeled J591 minibody were tested for uptake and retention of cell-associated radioactivity in the PSMA+ CWR22rv1 cells. The CWR22rv1 cells were selected as the sole PSMA+ cell line for these *in vitro* experiments since they will be used for the microPET imaging experiment. Drawing from the literature and the experimental knowledge of colleagues, the CWR22rv1 xenograft model has a higher tumor take rate and faster *in vitro* and tumor growth rates than the LNCaP model.

**[00121]** For the uptake and retention of the  $^{131}\text{I}$ -labeled J591 minibody, the amount of radioactivity associated with the membrane rapidly drops within the first 30 minutes whereas the internalized radioactivity rapidly increases in this timeframe (see Figure 19A). Together these data suggests the internalization of the  $^{131}\text{I}$ -J591 minibody. Although the amount of internalized  $^{131}\text{I}$  J591 increases over time, the total cell-associated radioactivity decreased substantially by 180 minutes relative to the initial starting point of  $\sim 2900$  cpm (see Figure 19A).

**[00122]** In sharp contrast, the uptake and retention of the  $^{111}\text{In}$ -DOTA labelled J591 minibody showed a relatively large increase in total cell-associated radioactivity over time (see Figure 19B). Similar to the  $^{131}\text{I}$  labelled J591 minibody, the membrane-associated radioactivity dramatically decreases as the internalized radioactivity

increases suggesting active internalization (see Figure 19B). Attributed in large part to the increase in internalized radioactivity over time, the total cell-associated radioactivity increased to approximately 20,000 cpm by 180 minutes from a starting point of ~7,500 cpm (Figure 19B).

**[00123]** To compare the two radiolabeled J591 minibodies, the total cell-associated radioactivity was normalized by expressing the data in terms of percentage of the initial cell-associated radioactivity for each respective radiolabel at t=0 (see Figure 20). By t= 180 minutes, the  $^{111}\text{In}$ -DOTA labeled J591 minibody increases to ~250% of the initial cell-associated radioactivity whereas the  $^{131}\text{I}$  labeled J591 minibody decreases to ~80% of the initial (Figure 20). As seen by other groups in the literature (Vaidyanathan et al 2009), a non-residualizing  $^{131}\text{I}$  labeling strategy resulted in an overall decrease in cell-associated radioactivity over time. These data clearly shows the retention and accumulation of cell-associated radioactivity over time for the residualizing  $^{111}\text{In}$ -DOTA radiolabel.

**[00124]** Purified J591 HC VHVL minibody (or any of the minibodies described above) may be used to demonstrate the ability to target human PSMA *in vivo* in microPET imaging and biodistribution studies. In one embodiment, the purified J591 HC VHVL minibody protein may first be validated again to confirm its ability to bind PSMA *in vitro* in preparation for the imaging studies. Upon confirmation of binding, the J591 HC VHVL minibody may then be conjugated to the bifunctional chelator DOTA and radiolabeled with an appropriate positron-emitting radiometal for microPET such as Copper 64. Radiolabeled minibody can be analyzed to ensure high radiolabeling efficiency and immunoreactivity before proceeding to microPET imaging.

**[00125]** In some embodiments, the radiolabeled minibody can be injected intravenously into xenograft mice implanted with either PSMA positive or PSMA negative tumors. At specific time points post-injection, each animal may be serially scanned by PET. After the final scan, animals may be scanned by CT for anatomical reference. The PET and CT images for each animal may then be analyzed to evaluate tumor targeting and specificity.

**Example 5: *In vivo* binding and biodistribution of  $^{124}\text{I}$ -J591 and  $^{64}\text{Cu}$ -DOTA-conjugated J591 minibodies**

**[00125]**      *Radiolabeling J591 minibody with Iodine-124.* Purified J591 minibody protein (total amount of 300  $\mu\text{g}$ ) was radiolabeled with approximately 1.3 mCi of  $^{124}\text{I}$  using the Iodogen method from Pierce Thermo Scientific (as described in Olafsen et al 2006). This method involves a chemical oxidation reaction to attach  $^{124}\text{I}$  radioisotope to available Tyrosine residues of the J591 minibody. Table 3, below, is a summary of the J591 minibody radiolabeling results including radiolabeling efficiency, percentage of bound radioactivity after purification, specific activity, and immunoreactivity. Following the labeling reaction, the radiolabeling efficiency was determined to be approximately 62% (percentage of radioactivity bound to the protein versus unbound) using instant thin layer chromatography (ITLC) (see Table 3). Radiolabeled J591 minibody was partially purified using Sephadex<sup>™</sup> G-25 spin columns and re-evaluated by ITLC to determine the percentage of bound radioactivity. The specific activity of the radiolabelled protein was 2.6  $\mu\text{Ci}/\mu\text{g}$  (Table 3), as determined by measuring the total radioactivity of the protein using a dose calibrator. To remove excess unbound  $^{124}\text{I}$  from the reaction, the radiolabeled protein was further purified using spin columns. The percentage of radioactivity bound to the J591 minibody following purification was dramatically increased to approximately 98% (Table 3). Immunoreactivity of the  $^{124}\text{I}$ -J591 minibody was determined to be 48% by testing binding to CWR22rv1 vs PC3 cells (Table 3). Although this immunoreactivity was lower than anticipated, the decision was made to move the  $^{124}\text{I}$  J591 minibody forward into the imaging and biodistribution experiment based on the previous binding performance of the minibody. Future optimizations to the radiolabeling conditions (pH, time, temperature, etc) and obtaining higher protein purity could potentially improve the immunoreactivity.

Table 3. Radiolabeling of the J591 Minibody with  $^{124}\text{I}$  and  $^{64}\text{Cu}$ .

|                                                            | Labelling Conditions               | Radiolabeling Efficiency (%) | % Bound Radioactivity Post-Purification | Specific Activity (uCi/ug) | Immunoreactivity (%) |
|------------------------------------------------------------|------------------------------------|------------------------------|-----------------------------------------|----------------------------|----------------------|
| $^{124}\text{I}$                                           | Protein in PBS                     | 62%                          | 98.0%                                   | 2.6                        | 48%                  |
| $^{64}\text{Cu}$ -DOTA                                     | Protein in PBS                     | 40%                          | 85% *                                   | 1 *                        | 29% *                |
| $^{64}\text{Cu}$ -DOTA                                     | AmmOAc, increase<br>AmmCitr buffer | 92%                          | 85% *                                   | 1 *                        | 29% *                |
| * - Fractions from both labelling conditions were combined |                                    |                              |                                         |                            |                      |

**[00127]** *Radiometal labeling the DOTA-J591 minibody with Copper-64.* J591 minibody, previously conjugated with the bifunctional metal chelator DOTA, was radiolabeled with  $^{64}\text{Cu}$ . For the initial radiolabeling condition, 400 $\mu\text{g}$  of the DOTA-J591 minibody in PBS was incubated with approximately 745  $\mu\text{Ci}$   $^{64}\text{CuCl}_2$  in 25mM metal-free ammonium citrate [pH 5.2] at 43C for 60 minutes. The reaction was stopped by the addition of 10mM EDTA to a final concentration of 1mM. Using these labeling conditions, radiolabeling efficiency was determined to be lower than anticipated at approximately 40% (see Table 3).

**[00128]** In an attempt to improve labeling efficiency, the DOTA-J591 minibody was first dialyzed into 0.25 ammonium acetate buffer [pH 7.2] before starting the radiolabeling reaction. An additional 560  $\mu\text{g}$  of the DOTA-J591 minibody, in the ammonium acetate buffer, was labeled with approximately 730 uCi of  $^{64}\text{CuCl}_2$ . Another adjustment to improve the radiolabeling involved increasing the percentage of ammonium citrate buffer used in the reaction. With these adjustments, the radiolabeling efficiency was dramatically increased to approximately 92% (Table 3).

**[00129]** All of the  $^{64}\text{Cu}$ -DOTA J591 minibody fractions from both labeling conditions were pooled together and further purified to remove excess unbound  $^{64}\text{Cu}$  using spin columns. The percentage of radioactivity attached to the J591 minibody following purification was approximately 85%, and the specific activity was 1  $\mu\text{Ci}/\mu\text{g}$  (Table 3). Immunoreactivity of the radiolabeled minibody was determined to be approximately 29% (Table 3) using the cell-based method described previously for  $^{124}\text{I}$  J591 minibody. Although the immunoreactivity was lower than expected, the decision

was made to move forward into the microPET and biodistribution experiment. In addition to the protein purity and the labeling conditions, future efforts to optimize immunoreactivity could include optimizing the DOTA conjugation reaction (i.e. DOTA-molecule ratio, etc).

#### **Example 6: Serial microPET imaging and biodistribution of radiolabeled J591 minibodies**

**[00130]** <sup>64</sup>Cu-DOTA J591 minibody. To evaluate the tumor targeting and binding specificity of the <sup>64</sup>Cu-DOTA-J591 minibody, microPET imaging and biodistribution analysis was performed using mice implanted with both CWR22rv1 (PSMA+) and PC3 (PSMA-) xenografts. Both xenograft tumors were grown to a size between 39-223 mg before starting the imaging experiment. The CT and PET/CT images, at 4 hours post-injection, showed rapid tumor localization at the CWR22rv1 tumor compared to the PC3 tumor (Figure 21A and 21B show a representative mouse). As expected for a radiometal labeled minibody, prominent activity was detected in thorax and particularly localized to the liver. Localization of the radiometals such as <sup>64</sup>Cu has been well-studied in the literature (Yazaki et al 2001). With the exception of the liver, background activity was relatively low even at 4 hours post-injection allowing for PET/CT images with remarkable contrast (Figure 21B and 21C). Strong tumor localization persisted at 19 hours and even 43 hours post-injection (Figure 21D). The overall background activity decreased slightly over time but the liver remained a strong source of activity (Figure 21D).

**[00131]** Following the final scan, all animals (n=8 at 19 hours and n=4 at 43 hours p.i.) were euthanized and selected tissues of interest (including the positive and negative tumors, blood, liver, spleen, lungs, and kidneys) were excised, weighed, and measured by a gamma counter for radioactivity. The biodistribution at 19 hours post-injection in Figure 22 showed that CWR22rv1 tumor (Tumor+) reached an average uptake of 8.23 %ID/g compared to 2.69 %ID/g for the PC3 tumor (Tumor-). Localization was significantly higher at the CWR22rv1 than PC3 tumor (p<0.05). As revealed by the microPET/CT imaging, uptake in the liver at 19 hours p.i. was relatively high (21.43

%ID/g) whereas the localization was much less prominent in the other tissues of interest (see Figure 22).

**[00132]** At 43 hours postinjection, the biodistribution reveals an increase in the average uptake at the CWR22rv1 tumor (Tumor+; 13.25 %ID/g) compared to 19 hours postinjection (Figure 22). Background activity decreased relative to 19 hours post-injection, particularly the significant decrease in liver activity to 14.37 %ID/g (Figure 22).

**[00133]** With the overall decrease in background activity combined with the increasing accumulation at the CWR22rv1 tumor, the tumor to background ratios increased dramatically between 19 hours postinjection to 43 hours postinjection (Figure 26).

**[00134]** <sup>124</sup>I J591 minibody. As with the <sup>64</sup>Cu-DOTA J591 minibody, microPET and biodistribution experiments were performed with the <sup>124</sup>I J591 minibody to evaluate tumor targeting. Both xenograft tumors were grown to a range in size between 36-192 mg before starting the imaging experiment. MicroPET images at 4 hours postinjection (p.i.) showed rapid localization at the CWR22rv1 tumor but high circulating activity in the thorax, abdomen, and bladder (Figure 23A and 23B). Background activity cleared significantly from the system by 20 hours postinjection and was almost completely absent by 44 hours while the activity at the positive tumor remained (Figure 23C).

**[00135]** For biodistribution analysis, all animals in a group were euthanized after the final scan (n=6 at 20 hours and n=2 at 44 hours p.i.) and the selected tissues of interest were excised, weighed, and measured by a gamma counter for radioactivity. The biodistribution at 20 hours post-injection for the mouse in Figure 24 showed that CWR22rv1 tumor (Tumor+) uptake reached 8.75 %ID/g compared to 1.8 %ID/g for the PC3 tumor (Tumor-). Localization was significantly higher at the CWR22rv1 than PC3 tumor (p<0.05). Background activity was relatively low by 20 hours p.i. (Figure 24).

**[00136]** By 44 hours post-injection, the CWR22rv1 tumor (Tumor+) uptake decreased substantially to 3.25 %ID/g (Figure 24). Supporting the previous results from the *in vitro* internalization and retention experiments described above, cell-associated

radioactivity decreased over time from dehalogenation and/or metabolism of the  $^{124}\text{I}$ -J591 minibody. Background activity was almost entirely cleared from the system by 44 hours p.i. (Figure 24).

**[00137]** Although the uptake of activity decreased at the CWR22rv1 tumor over time (Figure 24), the rapid decrease in background activity allowed a strong contrast for the images. The biodistribution ratios reflect this large increase in tumor to background over time (Figure 27).

**[00138]** Upon successful imaging of PSMA positive tumors by the J591 minibody, the biodistribution of the minibody may be investigated according to embodiments of the disclosure. These biodistribution studies can investigate the localization of the minibody at the tumor site versus other selected tissues over time following injection. These studies may be used to demonstrate high tumor to background ratios. Use of a J591 minibody would likely produce a high tumor to background ratio when imaging a tumor that overexpresses PSMA, such as in prostate cancer. Positive results from these imaging and biodistribution experiments may lead to toxicology experiments in preparation for clinical studies.

**[00139]** Further, the ability of a J591 minibody to target human PSMA *in vivo* by PET imaging studies may be demonstrated through clinical trials in cancer patients. In one embodiment, the clinical trials may be performed in prostate cancer patients. These clinical trials in cancer patients may be performed using similar methods as described above. Briefly, radiolabeled minibody can be injected intravenously into cancer patients having a form of cancer that is known to overexpress PSMA. At specific time points post-injection, each patient may be serially scanned by PET. After the final scan, patients may be scanned by CT for anatomical reference. The PET and CT images for each patient may then be analyzed to evaluate tumor targeting and specificity.

## REFERENCES

Bander NH, Trabulsi EJ, Kostakoglu L, Yao D, Vallabhajosula S, Smith-Jones P, Joyce MA, Milowsky M, Nanus DM, Goldsmith SJ. Targeting metastatic prostate cancer with radiolabeled monoclonal antibody J591 to the extracellular domain of prostate specific membrane antigen. *J Urol*, 2003. 170 (5): 1717-1721.

Bander NH, Milowsky MI, Nanus DM, Kostakoglu L, Vallabhajosula S, Goldsmith SJ. Phase I trial of 177 Lutetium-labeled J591, a monoclonal antibody to prostate-specific membrane antigen, in patients with androgen-independent prostate cancer. *J Clin Oncol*, 2005. 23(21): 4591-601.

Hu S, Shively L, Wu AM. Minibody: A novel engineered anti-carcinoembryonic antigen antibody fragment (single-chain Fv-CH3) which exhibits rapid, high-level targeting of xenografts. *Cancer Res*, 1996. 56(13):3055-61.

Kukis DL, Denardo GL, Denardo SJ, Mirick GR, Miers LA, Greiner DP, Meares CF. Effect of the Extent of Chelate Substitution on the Immunoreactivity and Biodistribution of 21T-BAT-Lym-1 Immunoconjugates, 1995. 55, 878-884.

Lewis MR, Kao JY, Anderson AL, Shively JE, Raubitschek A. An improved method for conjugating monoclonal antibodies with N-hydroxysulfosuccinimidyl DOTA. *Bioconjug Chem*, 2001. 12: 320-324.

Leyton JV, Wu AM. Humanized radioiodinated minibody for imaging of prostate stem cell antigen-expressing tumors. *Clin Cancer Res*, 2008. 14(22):7488-96.

Liu H, Rajasekaran AK, Moy P, Xia Y, Kim S, Navarro V, Rahmati R, Bander NH. Constitutive and Antibody-induced Internalization of Prostate-specific Membrane Antigen. *Cancer Res*, 1998. 58: 4055-4060.

Liu H, Moy P, Kim S, Xia Y, Rajasekaran A, Navarro V, Knudsen B, Bander NH. Monoclonal antibodies to the extracellular domain of prostate specific membrane antigen also react with tumor vasculature endothelium. *Cancer Res*, 1997. 57(17): 3629-34.

Milowsky MI, Nanus DM, Kostakoglu L, Vallabhajosula S, Goldsmith SJ, Bander NH. Phase I trial of Yttrium-90-labeled anti-prostate specific membrane antigen monoclonal antibody J591 for androgen-independent prostate cancer. *J Clin Oncol*, 2004. 22(13): 2522-2531.

Milowsky MI, Nanus DM, Kostakoglu L, Sheehan CE, Vallabhajosula S, Goldsmith SJ, Ross JS, Bander NH. Vascular targeted therapy with anti-prostate-specific membrane antigen monoclonal antibody J591 in advanced solid tumors. *J Clin Oncol*, 2007. 25(5): 540-547.

Morris MJ, Divgi CR, Pandit-Taskar N, et al. Pilot trial of unlabeled and indium-111-labeled anti-prostate-specific membrane antigen antibody J591 for castrate metastatic prostate cancer. *Clin Cancer Res*, 2005. 11 (20): 7454-7461.

Olafsen T, Tan GJ, Cheung CW, Yazaki PJ, Park JM, Shively JE, Williams LE, Raubitschek AA, Press MF, Wu AM. Characterization of engineered anti-p185HER-2 (scFv-CH3)<sub>2</sub> antibody fragments (minibodies) for tumor targeting. *Protein Eng Des Sel*, 2004. 17(4):315-23.

Olafsen T, Kenanova VE, Wu AM. Tunable pharmacokinetics: modifying the in vivo half-life of antibodies by directed mutagenesis of the Fc fragment. *Nat Protoc*, 2006. 1:2048-60.

Olafsen T, Betting D, Kenanova VE, Salazar FB, Clarke P, Said J, Raubitschek AA, Timmerman JM, Wu AM. Recombinant Anti-CD20 Antibody Fragments for Small-Animal PET Imaging of B-Cell Lymphomas. *J Nuc Med*, 2009. 50(9):1500-1508.

Olson WC, Heston WDW, Rajasekaran AK. Clinical Trials of Cancer Therapies Targeting Prostate Specific Membrane Antigen. *Reviews on Recent Clinical Trials*, 2007. 2 : 182-190.

Slovin SF. Targeting novel antigens for prostate cancer treatment: focus on prostate-specific membrane antigen. *Expert Opin Ther Targets*, 2005. 9(3): 561-570.

Vaidynathan G, Jestin E, Olafsen T, Wu AM, Zalutsky MR. Evaluation of an anti-p185(HER2)(scFv-C(H)2-C(H)3)2 fragment following radioiodination using two different residualizing labels: SGMIB and IB-Mal-D-GEEEEK. *Nucl Med Biol*, 2009. 36(6): 671-80.

Wong JY, Chu DZ, Williams LE, Yamauchi DM, Ikle DN, Kwok CS, Liu A, Wilczynski S, Colcher D, Yazaki PJ, Shively JE, Wu AM, Raubitschek AA. Pilot trial evaluating an <sup>123</sup>I-labeled 80-kilodalton engineered anticarcinoembryonic antigen antibody fragment (cT84.66 minibody) in patients with colorectal cancer. *Clin Cancer Res*, 2004. 10(15):5014-21.

Wu AM and Senter PD. Arming antibodies: prospects and challenges for immunoconjugates. *Nat Biotechnol*, 2005. 23(9):1137-46.

Wu AM and Olafsen T. Antibodies for molecular imaging of cancer. *Cancer J*, 2008. 14(3):191-7.

Wu AM. Antibodies and Antimatter: The resurgence of ImmunoPET. *J Nucl Med*, 2009. 50(1):2-5.

Yazaki PJ, Wu AM, Tsai SW, Williams LE, Ikle DN, Wong JYC, Shively JE, and Raubitschek AA. Tumor targeting of radiometal labeled anti-CEA recombinant T84.66 diabody and T84.66 minibody: Comparison to radioiodinated fragments. Bioconj Chem, 2001. 12, 220-228.

Patents and Published Patent Applications:

Wu, Anna. Antibody Construct. US Patent 5837821, filed 06/24/94, and issued 11/17/98.

Bander, Neil. Treatment and diagnosis of cancer. US Patent 6649163, filed 7/20/99, and issued 11/18/03.

Bander, Neil. Treatment and diagnosis of cancer. US Patent 6770450, filed 7/20/99, and issued 8/3/04.

Bander, Neil. Carr, Francis. Hamilton, Anita. Modified antibodies to prostate-specific membrane antigen and uses thereof. US Patent 7045605, filed 5/30/02, and issued 5/16/06.

Bander, Neil. Treatment and diagnosis of prostate cancer. US Patent 7112412, filed 7/20/99, and issued 9/26/06.

Bander, Neil. Treatment and diagnosis of cancer. US Patent 7163680, filed 8/13/2001, and issued 1/16/07.

Bander, Neil. Treatment and diagnosis of cancer. US Patent 6136311, filed 7/17/97, and issued 10/24/00.

Bander, Neil. Treatment and diagnosis of prostate cancer with antibodies to extracellular PSMA. US Patent 6107090, filed 4/9/97, and issued 8/22/00.

Bander, Neil. Carr, Francis. Hamilton, Anita. Methods of treating prostate cancer with anti-prostate specific membrane antigen antibodies. US Patent 7514078, filed 05/30/03, and issued 4/7/09.

What is claimed is:

1. A minibody comprising:
  - an scFv sequence that can bind prostate specific membrane antigen (PSMA), the scFv sequence comprising a variable heavy domain (VH) linked to a variable light domain (VL) by an amino acid linker sequence;
  - an artificial hinge sequence comprising a portion of a human IgG1 hinge and a GlySer linker; and
  - a human IgG CH3 sequence,wherein at least one of:
  - a) the VH is a variable heavy domain in SEQ ID NO:10 and the VL is a variable light domain in SEQ ID NO:10; or
  - b) the VH is a variable heavy domain in SEQ ID NO:3 and the VL is a variable light domain in SEQ ID NO:17.
2. The minibody of claim 1, wherein the VH is a variable heavy domain in SEQ ID NO:10 and the VL is a variable light domain in SEQ ID NO:10.
3. The minibody of claim 1, wherein the VH is a variable heavy domain in SEQ ID NO:3 and the VL is a variable light domain in SEQ ID NO:17.
4. The minibody of claim 1, wherein the VH is of the amino acid sequence consisting of SEQ ID NO:3 and the VL is of the amino acid sequence consisting of SEQ ID NO:17.
5. The minibody of any one of claims 1 to 4, further comprising an N-terminus signal sequence to enable secretion of the minibody when expressed in a cell.
6. The minibody of claim 1, wherein the scFv is in a VHVL orientation such that the VH is upstream of the VL.

7. The minibody of claim 6, wherein the minibody is encoded by the nucleotide sequence of SEQ ID NO:1.
8. The minibody of claim 1, wherein the scFv is in a VLVH orientation such that the VL is upstream of the VH.
9. The minibody of claim 1, wherein the minibody comprises the amino acid sequence of SEQ ID NO:10.
10. The minibody of any one of claims 1 to 9, wherein the minibody is conjugated to a diagnostic agent.
11. The minibody of claim 10, wherein the diagnostic agent is selected from the group consisting of a radioactive substance, a dye, a contrast agent, a fluorescent molecule, a bioluminescent compound, a bioluminescent molecule, an enzyme, an enhancing agent, a quantum dot, and a metal nanoparticle.
12. The minibody of any one of claims 1 to 9, wherein the minibody is labeled with a radioisotope.
13. Use of the minibody of any one of claims 10 to 12 in the manufacture of a medicament for diagnosing a cancer associated with PSMA expression.
14. Use of the minibody of any one of claims 10 to 12 for diagnosing a cancer associated with PSMA expression.
15. The use of claim 14, wherein the minibody is configured for administration to a subject having or suspected of having a cancer associated with PSMA expression;  
the minibody is configured for visualization using an imaging method to visualize the minibody *in vivo*; and

the minibody is configured for determining that the subject has a cancer associated with PSMA expression when the minibody localizes to a tumor site.

16. The use of any one of claims 13 to 15, wherein the minibody comprises SEQ ID NO:10.

17. The use of any one of claims 13 to 16, wherein the minibody targets neovasculature of a solid tumor.

18. The use of any one of claims 13 to 17, wherein the cancer associated with PSMA expression in a subject is prostate cancer, lung cancer, colorectal cancer, breast cancer, renal cancer, liver cancer, bladder cancer, pancreatic cancer or melanoma.

19. Use of the minibody of any one of claims 1 to 12 for treating a cancer associated with PSMA expression.

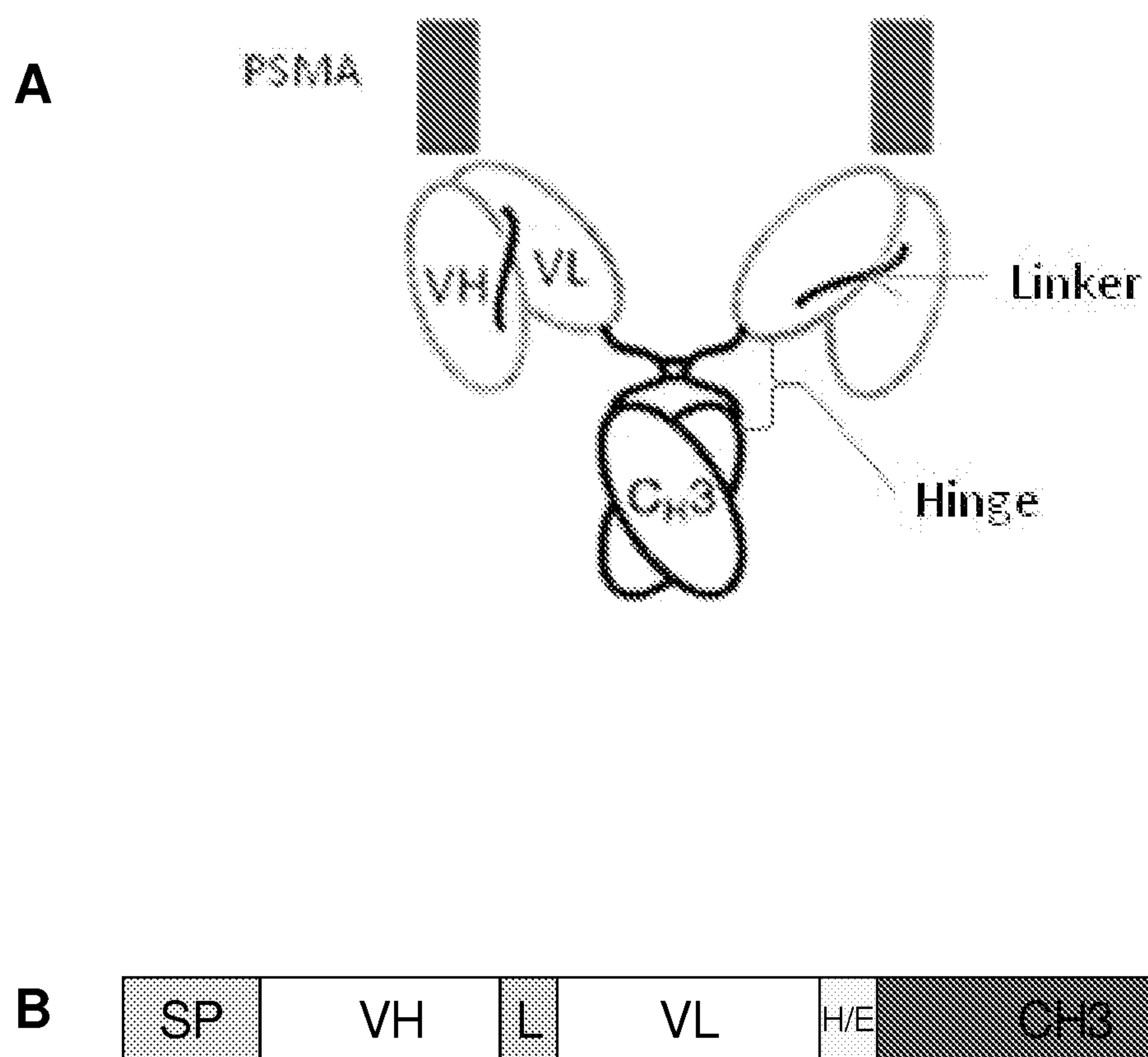
20. Use of the minibody of any one of claims 1 to 12 in the manufacture of a medicament for treating a cancer associated with PSMA expression.

21. The use of claim 19 or 20, wherein the minibody comprises SEQ ID NO:10.

22. The use of any one of claims 19 or 20, wherein the anti-PSMA minibody is conjugated to a therapeutic agent.

23. The use of claim 22, wherein the therapeutic agent is selected from the group consisting of: a chemotherapeutic agent, a therapeutic antibody, a therapeutic antibody fragment, a toxin, a radioisotope, an enzyme, a nuclease, a hormone, an immunomodulator, an antisense oligonucleotide, a chelator, a boron compound, a photoactive agent and a dye.

24. The use of any one of claims 19 to 23, wherein the minibody targets neovasculature of a solid tumor.
25. The use of any one of claims 19 to 24, wherein the cancer associated with PSMA expression in a subject is prostate cancer, lung cancer, colorectal cancer, breast cancer, renal cancer, liver cancer, bladder cancer, pancreatic cancer or melanoma.
26. A minibody comprising:
- an scFv sequence that can bind prostate specific membrane antigen (PSMA), the scFv comprising a variable heavy domain (VH) linked to a variable light domain (VL) by a linker amino acid sequence;
  - an artificial hinge sequence comprising a portion of a human IgG1 hinge and a GlySer linker; and
  - a human IgG CH3 sequence,
- wherein the VH is a variable heavy domain in SEQ ID NO:5 and the VL is a variable light domain in SEQ ID NO:19.

**Fig. 1**

VH

(SEQ ID NO:3) Line 1 EVQLPSGFEKKPGSVISCKTSGYTFTEYTIHWVKQSALEWIGNINPNNGGTT  
(SEQ ID NO:4) Line 2 EVQLQSGPELKKPGTSVRISCKTSGYTFTEYTIHWVKQSHGKSLLEWIGNINPNNGGTT  
(SEQ ID NO:5) Line 3 EVQLPSGPEKKPGSVISCKTSGYTFTEYTIHWVKQSALEWIGNINPNNGGTT

(SEQ ID NO:3) Line 1 YNQKFEIATLTVDKSSSTAYMEISLSEI AVYYCARGNFDYWGQGTFTVSS  
(SEQ ID NO:4) Line 2 YNQKFEDKATLTVDKSSSTAYMEISLSEI SEDSAVYYCARGNFDYWGQGTFTVSS  
(SEQ ID NO:5) Line 3 YNQKFEDKATLTVDKSSSTAYMEISLSEI AVYYCARGNFDYWGQGTFTVSS

VL

(SEQ ID NO:17) Line 1 DIVMTQSSSVGDRVITCKASQDVGTAVDWYQKPCPKLLIYNASTRHTG  
(SEQ ID NO:18) Line 2 DIVMTQSHKENSTSVGDRVITCKASQDVGTAVDWYQKPCPKLLIYNASTRHTG  
(SEQ ID NO:19) Line 3 DIVMTQSSSVGDRVITCKASQDVGTAVDWYQKPCPKLLIYNASTRHTG

(SEQ ID NO:17) Line 1 VPDEFTSGSGTDFTLTI CSDADYFCQQXNSYPLTFQSTLKK  
(SEQ ID NO:18) Line 2 VPDEFTSGSGTDFTLTIITNVQSEDLADYFCQQXNSYPLTFQAGTMLDLK  
(SEQ ID NO:19) Line 3 FPFPSGSGTDFTLTI CSDADYFCQQXNSYPLTFQSTLKK

Fig. 2

**Figure 3- J591 HC VHVL Minibody Translated Sequence (SEQ ID NOs:1 and 10)**

tctagagccgccacc

**XbaI Kozak**

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1  M E T D T L L L W V L L L W V P G S T G
1  ATGGAAACCGACACCCTGCTGCTGTGGGTGCTGCTGCTCTGGGTCCCAGGCTCCACCGGT
Signal Peptide
21  E V Q L V Q S G A E V K K P G A S V K I
61  GAAGTGCAGCTGGTGCAGTCTGGCGCCGAAGTGAAGAAACCTGGCGCCTCCGTGAAGATC
VH
41  S C K T S G Y T F T E Y T I H W V K Q A
121 TCCTGCAAGACCTCCGGCTACACCTTCACCGAGTACACCATCCACTGGGTGAAACAGGCC

61  S G K G L E W I G N I N P N N G G T T Y
181 TCCGGCAAGGGCCTGGAATGGATCGGCAACATCAACCCTAACAACGGCGGCACCACCTAC

81  N Q K F E D R A T L T V D K S T S T A Y
241 AACCAGAAGTTCGAGGACCGGGCCACCCTGACCGTGGACAAGTCCACCTCCACCGCCTAC

101 M E L S S L R S E D T A V Y Y C A A G W
301 ATGGAAGTGTCTCCCTGCGGTCTGAGGACACCGCCGTGTACTACTGCGCCGCTGGCTGG

121 N F D Y W G Q G T T V T V S S G S T S G
361 AACTTCGACTACTGGGGCCAGGGCACCACAGTGACAGTCTCGAGCGGCTCTACCTCTGGC
Linker
141 G G S G G G S G G G G S S D I V M T Q S
421 GGAGGCTCTGGGGGAGGAAGCGGCGGAGGCGGCTCCTCTGACATCGTGATGACCCAGTCC
VL
161 P S S L S A S V G D R V T I T C K A S Q
481 CCCTCCTCCCTGTCTGCCTCCGTGGGCGACAGAGTGACCATCACATGCAAGGCCTCCCAG

181 D V G T A V D W Y Q Q K P G K A P K L L
541 GATGTGGGCACCGCCGTGGACTGGTATCAGCAGAAGCCTGGCAAGGCCCTAAGCTGCTG

201 I Y W A S T R H T G V P D R F T G S G S
601 ATCTACTGGGCCTCCACCAGACACACCGGCGTGCCTGACAGATTACCGGCTCCGGCTCT

221 G T D F T L T I S S L Q P E D F A D Y F
661 GGCACCGACTTCACCCTGACCATCTCCAGCCTGCAGCCTGAGGACTTCGCCGACTACTTC

241 C Q Q Y N S Y P L T F G G G T K L E I K
721 TGCCAGCAGTACAACCTCCTACCTCTGACCTTCGGCGGAGGCACCAAGCTGGAAATCAAA

261 E P K S C D K T H T C P P C G G G S S G
781 GAGCCCAAGTCCTGCGACAAGACCCACACCTGTCCCCCTTGTGGCGGCGGATCTAGTGGC
Hinge
281 G G S G G Q P R E P Q V Y T L P P S R D
841 GGAGGATCCGGTGGCCAGCCTCGGGAGCCTCAGGTGTACACCCTGCCTCCCTCCCGGGAC
CH3
301 E L T K N Q V S L T C L V K G F Y P S D
901 GAGCTGACCAAGAACCAGGTGTCCCTGACCTGTCTGGTCAAGGGCTTCTACCCTTCCGAT

321 I A V E W E S N G Q P E N N Y K T T P P
961 ATCGCCGTGGAGTGGGAGTCCAACGGCCAGCCTGAGAACAACCTACAAGACCACCCCTCCT

341 V L D S D G S F F L Y S K L T V D K S R

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**Figure 3 (cont'd)**

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1021 GTGCTGGACTCCGACGGCTCCTTCTTCCTGTACTCCAAGCTGACAGTGGATAAGTCCCGG
      361 W Q Q G N V F S C S V M H E A L H N H Y
1081 TGGCAGCAGGGCAACGTGTTCTCCTGTTCCGTGATGCACGAGGCCCTGCACAACCACTAT
      381 T Q K S L S L S P G K -
1141 ACCCAGAAGTCCCTGTCCCTGTCTCCTGGCAAGTGA
                                STOP
```

aagctt  
HindIII

**Figure 4- J591 2P VHVL Minibody Translated Sequence (SEQ ID NOs:2 and 11)**

TCTAGAGCCGCCACC

**XbaI**

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1  M E T D T L L L W V L L L W V P G S T G
1  ATGGAAACCGACACCCTGCTGCTGTGGGTGCTGCTGCTCTGGGTCCCAGGCTCCACCGGT
   Signal Peptide
21  E V Q L V Q S G P E V K K P G A T V K I
61  GAAGTGCAGCTGGTGCAGTCCGCCCTGAAGTGAAGAAGCCTGGCGCCACCGTCAAGATC
   VH
41  S C K T S G Y T F T E Y T I H W V K Q A
121 TCTTGCAAGACCTCCGGCTACACCTTCACCGAGTACACCATCCACTGGGTGAAACAGGCC

61  P G K G L E W I G N I N P N N G G T T Y
181 CCTGGCAAGGGTCTGGAATGGATCGGCAACATCAACCCTAACAACGGCGGCACCACCTAT

81  N Q K F E D K A T L T V D K S T D T A Y
241 AACCAGAAGTTCGAGGACAAGGCCACCCTGACCGTGGACAAGTCCACCGACACCGCCTAC

101 M E L S S L R S E D T A V Y Y C A A G W
301 ATGGAAGTGTCTCCCTCCGTCCGAGGACACCGCAGTGTATTACTGCGCCGCTGGCTGG

121 N F D Y W G Q G T L L T V S S G S T S G
361 AACTTCGACTACTGGGGCCAGGGCACCCTGCTGACAGTCTCGAGCGGCTCCACAAGTGGC
   Linker
141 G G S G G G S G G G G S S D I Q M T Q S
421 GGAGGCTCTGGCGGTGGATCTGGCGGAGGCGGCTCATCCGACATCCAGATGACCCAGTCC
   VL
161 P S S L S T S V G D R V T L T C K A S Q
481 CCCTCCTCCCTGTCCACCTCCGTGGGCGACAGAGTGACCCTGACATGCAAGGCCTCCAG

181 D V G T A V D W Y Q Q K P G Q S P K L L
541 GACGTGGGCACCGCCGTGGACTGGTATCAGCAGAAGCCAGGCCAGTCCCCTAAGCTGCTG

201 I Y W A S T R H T G I P S R F S G S G S
601 ATCTACTGGGCCTCCACCCGGCACACCGGCATCCCTTCCCGGTTCTCCGGCAGTGGCTCT

221 G T D F T L T I S S L Q P E D F A D Y Y
661 GGCACCGACTTCACCCTGACCATCTCCAGCCTGCAGCCTGAGGACTTCGCCGACTACTAC

241 C Q Q Y N S Y P L T F G A G T K V D I K
721 TGCCAGCAGTACAACCTCCTACCCTCTGACCTTCGGCGCCGGCACAAAGGTGGACATCAAA

261 E P K S C D K T H T C P P C G G G S S G
781 GAGCCTAAGTCCTGCGACAAGACCCACACATGTCCCCCTTGCGGCGGAGGAAGCAGCGGA
   Hinge Extension
281 G G S G G Q P R E P Q V Y T L P P S R D
841 GGCGGATCCGGTGGCCAGCCTCGGGAGCCTCAGGTGTACACCCTGCCTCCCTCCCGGGAC
   CH3
301 E L T K N Q V S L T C L V K G F Y P S D
901 GAGCTGACCAAGAACCAGGTGTCCCTGACCTGTCTGGTCAAGGGCTTCTACCCTTCCGAT

321 I A V E W E S N G Q P E N N Y K T T P P
961 ATCGCCGTGGAGTGGGAGTCCAACGGCCAGCCTGAGAACAACCTACAAGACCACCCCTCCT

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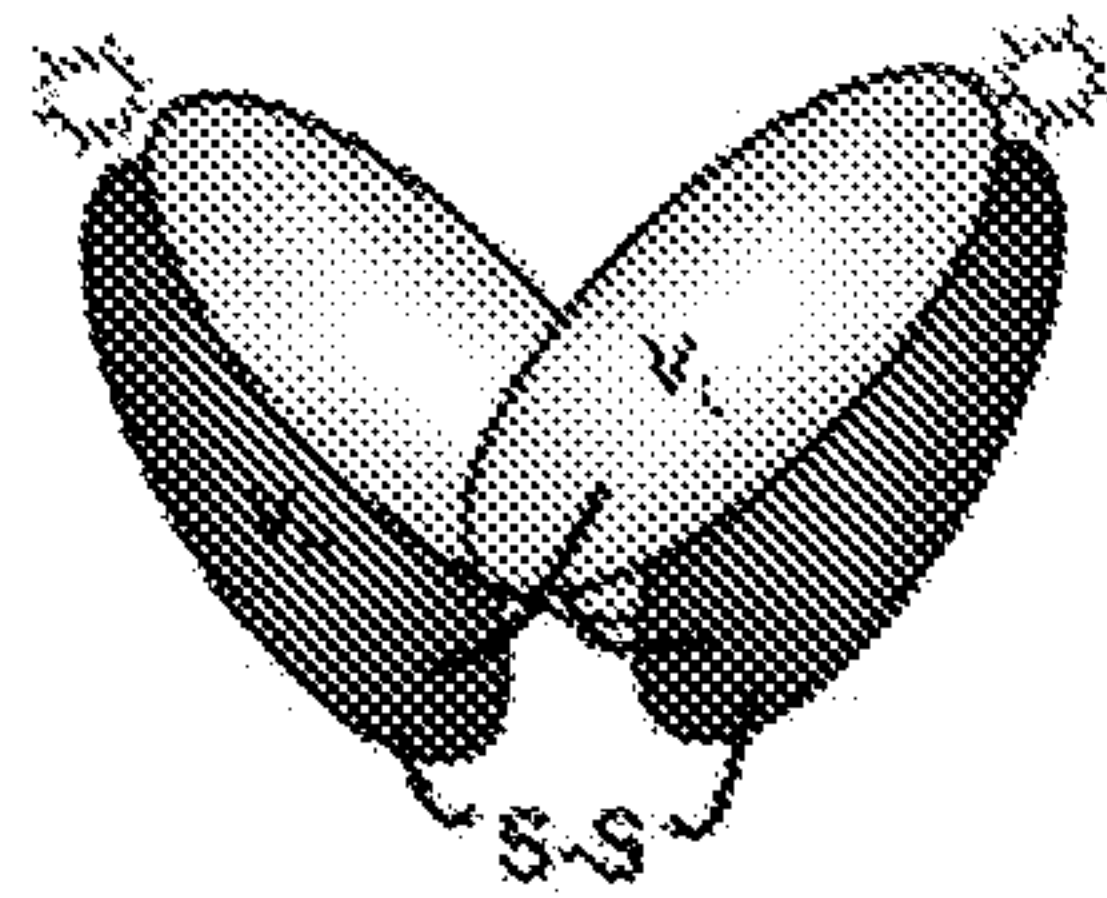
**Figure 4- cont'd**

341 V L D S D G S F F L Y S K L T V D K S R  
1021 GTGCTGGACTCCGACGGCTCCTTCTTCCTGTACTCCAAGCTGACAGTGGATAAGTCCCGG

361 W Q Q G N V F S C S V M H E A L H N H Y  
1081 TGGCAGCAGGGCAACGTGTTCTCCTGTTCCTGTGATGCACGAGGCCCTGCACAACCACTAT

381 T Q K S L S L S P G K -  
1141 ACCCAGAAGTCCCTGTCCCTGTCTCCTGGCAAGTGA  
STOP

AAGCTT  
**HinDIII**

**A**

Cys Diabody (Sirk S. et al, Bioconjugate Chem, 2008)

**B**

5 or 8 aa

**C**

5 or 8 aa



**Fig. 5**

**Figure 6 (SEQ ID NOs 6 and 12)**

J591 CysDB Vh-5-Vl

```
1   M E T D T L L L W V L L L W V P G S T G
1   ATGGAAACCGACACCCTGCTGCTGTGGGTGCTGCTCCTGTGGGTGCCC GGATCTACCGGT
   Signal
21  E V Q L V Q S G A E V K K P G A S V K I
61  GAAGTGCAGCTGGTGCAGTCTGGCGCCGAAGTGAAGAAACCTGGCGCCTCCGTGAAGATC
   Vh
41  S C K T S G Y T F T E Y T I H W V K Q A
121 TCCTGCAAGACCTCCGGCTACACCTTCACCGAGTACACCATCCACTGGGTGAAACAGGCC

61  S G K G L E W I G N I N P N N G G T T Y
181 TCCGGCAAGGGCCTGGAATGGATCGGCAACATCAACCCTAACACGGCGGCACCACCTAC

81  N Q K F E D R A T L T V D K S T S T A Y
241 AACCAGAAGTTCGAGGACCGGGCCACCCTGACCGTGGACAAGTCCACCTCCACCGCCTAC

101 M E L S S L R S E D T A V Y Y C A A G W
301 ATGGAAGTGTCTCCCTGCGGTCTGAGGACACCGCCGTGTACTACTGCGCCGCTGGCTGG

121 N F D Y W G Q G T T V T V S S S G G G G
361 AACTTCGACTACTGGGGCCAGGGCACCACCGTGACAGTCTCGAGCTCCGGTGGGGGCGGC
   Linker
141 D I V M T Q S P S S L S A S V G D R V T
421 GATATCGTGATGACCCAGTCCCCTTCCTCCCTGTCTGCCTCCGTGGGCGACAGAGTGACC
   Vl
161 I T C K A S Q D V G T A V D W Y Q Q K P
481 ATCACATGCAAGGCCTCCCAGGATGTGGGCACCGCCGTGGACTGGTATCAGCAGAAGCCT

181 G K A P K L L I Y W A S T R H T G V P D
541 GGCAAGGCCCCCTAAGCTGCTGATCTACTGGGCCTCCACCAGACACACCGGCGTGCCTGAC

201 R F T G S G S G T D F T L T I S S L Q P
601 AGATTACCGGCTCCGGCTCTGGCACCGACTTCACCCTGACCATCTCCAGCCTGCAGCCT

221 E D F A D Y F C Q Q Y N S Y P L T F G G
661 GAGGACTTCGCCGACTACTTCTGCCAGCAGTACAACCTCCTACCCTCTGACCTTCGGCGGA

241 G T K L E I K G G C
721 GGCACCAAGCTGGAAATCAAGGGCGGTTGC
   Cys
```

**Figure 7 (SEQ ID NOs 7 and 13)**

J591 CysDB Vh-8-V1

```

1   M E T D T L L L W V L L L W V P G S T G
1   ATGGAAACCGACACCCTGCTGCTGTGGGTGCTGCTCCTGTGGGTGCCC GGATCTACCGGT
   Signal
21  E V Q L V Q S G A E V K K P G A S V K I
61  GAAGTGCAGCTGGTGCAGTCTGGCGCCGAAGTGAAGAAACCTGGCGCCTCCGTGAAGATC
   Vh
41  S C K T S G Y T F T E Y T I H W V K Q A
121 TCCTGCAAGACCTCCGGCTACACCTTCACCGAGTACACCATCCACTGGGTGAAACAGGCC

61  S G K G L E W I G N I N P N N G G T T Y
181 TCCGGCAAGGGCCTGGAATGGATCGGCAACATCAACCCTAACACGGCGGCACCACCTAC

81  N Q K F E D R A T L T V D K S T S T A Y
241 AACCAGAAGTTCGAGGACCGGGCCACCCTGACCGTGGACAAGTCCACCTCCACCGCCTAC

101 M E L S S L R S E D T A V Y Y C A A G W
301 ATGGAAGTGTCTCCCTGCGGTCTGAGGACACCGCCGTGTACTACTGCGCCGCTGGCTGG

121 N F D Y W G Q G T T V T V S S G G G S G
361 AACTTCGACTACTGGGGCCAGGGCACCACCGTGACAGTCTCGAGCGGCGGAGGGAGTGGC
   Linker
141 G G G D I V M T Q S P S S L S A S V G D
421 GGAGGCGGCGATATCGTGATGACCCAGTCCCCTTCCTCCCTGTCTGCCTCCGTGGGCGAC
   V1
161 R V T I T C K A S Q D V G T A V D W Y Q
481 AGAGTGACCATCACATGCAAGGCCTCCCAGGATGTGGGCACCGCCGTGGACTGGTATCAG

181 Q K P G K A P K L L I Y W A S T R H T G
541 CAGAAGCCTGGCAAGGCCCTAAGCTGCTGATCTACTGGGCCTCCACCAGACACACCGGC

201 V P D R F T G S G S G T D F T L T I S S
601 GTGCCTGACAGATTACCGGCTCCGGCTCTGGCACCGACTTCACCCTGACCATCTCCAGC

221 L Q P E D F A D Y F C Q Q Y N S Y P L T
661 CTGCAGCCTGAGGACTTCGCCGACTACTTCTGCCAGCAGTACAACCTCCTACCCTCTGACC

241 F G G G T K L E I K G G C
721 TTCGGCGGAGGCACCAAGCTGGAAATCAAGGGCGGTTGC
   cys

```

**Figure 8 (SEQ ID NOs 8 and 14)**

J591 CysDB V1-5-Vh

```
1   M E T D T L L L W V L L L W V P G S T G
1   ATGGAAACCGACACCCTGCTGCTGTGGGTGCTGCTCCTGTGGGTGCCCGGATCTACCGGT
   Signal
21  D I V M T Q S P S S L S A S V G D R V T
61  GATATCGTGATGACCCAGTCCCCTTCCCTCCCTGTCTGCCTCCGTGGGCGACAGAGTGACC
   V1
41  I T C K A S Q D V G T A V D W Y Q Q K P
121 ATCACATGCAAGGCCTCCCAGGATGTGGGCACCGCCGTGGACTGGTATCAGCAGAAGCCT

61  G K A P K L L I Y W A S T R H T G V P D
181 GGCAAGGCCCTAAGCTGCTGATCTACTGGGCCTCCACCAGACACACCGGCGTGCCTGAC

81  R F T G S G S G T D F T L T I S S L Q P
241 AGATTCACCGGCTCCGGCTCTGGCACCGACTTCACCCTGACCATCTCCAGCCTGCAGCCT

101 E D F A D Y F C Q Q Y N S Y P L T F G G
301 GAGGACTTCGCCGACTACTTCTGCCAGCAGTACAACTCCTACCCTCTGACCTTCGGCGGA

121 G T K L E I K S G G G G E V Q L V Q S G
361 GGCACCAAGCTGGAAATCAAGTCCGGTGGGGGCGGCGAAGTGCAGCTGGTGCAGTCTGGC
   Linker Vh
141 A E V K K P G A S V K I S C K T S G Y T
421 GCCGAAGTGAAGAAACCTGGCGCCTCCGTGAAGATCTCCTGCAAGACCTCCGGCTACACC

161 F T E Y T I H W V K Q A S G K G L E W I
481 TTCACCGAGTACACCATCCACTGGGTGAAACAGGCCTCCGGCAAGGGCCTGGAATGGATC

181 G N I N P N N G G T T Y N Q K F E D R A
541 GGCAACATCAACCCTAACAACGGCGGCACCACCTACAACCAGAAGTTCGAGGACCGGGCC

201 T L T V D K S T S T A Y M E L S S L R S
601 ACCCTGACCGTGGACAAGTCCACCTCCACCGCCTACATGGAAGTGTCTCCCTGCGGTCT

221 E D T A V Y Y C A A G W N F D Y W G Q G
661 GAGGACACCGCCGTGTACTACTGCGCCGCTGGCTGGAAGTTCGACTACTGGGGCCAGGGC

241 T T V T V S S G G C
721 ACCACCGTGACAGTCTCGAGCGGCGGTTGC
   Cys
```

**Figure 9 (SEQ ID NOs 9 and 15)**

J591 CysDB V1-8-Vh

```
1   M E T D T L L L W V L L L W V P G S T G
1   ATGGAAACCGACACCCTGCTGCTGTGGGTGCTGCTCCTGTGGGTGCCCGGATCTACCGGT
   Signal
21  D I V M T Q S P S S L S A S V G D R V T
61  GATATCGTGATGACCCAGTCCCCTTCCCTCCCTGTCTGCCTCCGTGGGCGACAGAGTGACC
   V1
41  I T C K A S Q D V G T A V D W Y Q Q K P
121 ATCACATGCAAGGCCTCCCAGGATGTGGGCACCGCCGTGGACTGGTATCAGCAGAAGCCT

61  G K A P K L L I Y W A S T R H T G V P D
181 GGCAAGGCCCTAAGCTGCTGATCTACTGGGCCTCCACCAGACACACCGGCGTGCCTGAC

81  R F T G S G S G T D F T L T I S S L Q P
241 AGATTCACCGGCTCCGGCTCTGGCACCGACTTCACCCTGACCATCTCCAGCCTGCAGCCT

101 E D F A D Y F C Q Q Y N S Y P L T F G G
301 GAGGACTTCGCCGACTACTTCTGCCAGCAGTACAACTCCTACCCTCTGACCTTCGGCGGA

121 G T K L E I K G G G S G G G G E V Q L V
361 GGCACCAAGCTGGAAATCAAGGGCGGAGGGAGTGGCGGAGGCGGCGAAGTGCAGCTGGTG
   Linker Vh
141 Q S G A E V K K P G A S V K I S C K T S
421 CAGTCTGGCGCCGAAGTGAAGAAACCTGGCGCCTCCGTGAAGATCTCCTGCAAGACCTCC

161 G Y T F T E Y T I H W V K Q A S G K G L
481 GGCTACACCTTCACCGAGTACACCATCCACTGGGTGAAACAGGCCTCCGGCAAGGGCCTG

181 E W I G N I N P N N G G T T Y N Q K F E
541 GAATGGATCGGCAACATCAACCCTAACAACGGCGGCACCACCTACAACCAGAAGTTCGAG

201 D R A T L T V D K S T S T A Y M E L S S
601 GACCGGGCCACCCTGACCGTGGACAAGTCCACCTCCACCGCCTACATGGAAGTGTCTCTCC

221 L R S E D T A V Y Y C A A G W N F D Y W
661 CTGCGGTCTGAGGACACCGCCGTGTACTACTGCGCCGCTGGCTGGAAGTTCGACTACTGG

241 G Q G T T V T V S S G G C
721 GGCCAGGGCACCACCGTGACAGTCTCGAGCGGCGGTTGC
   Cys
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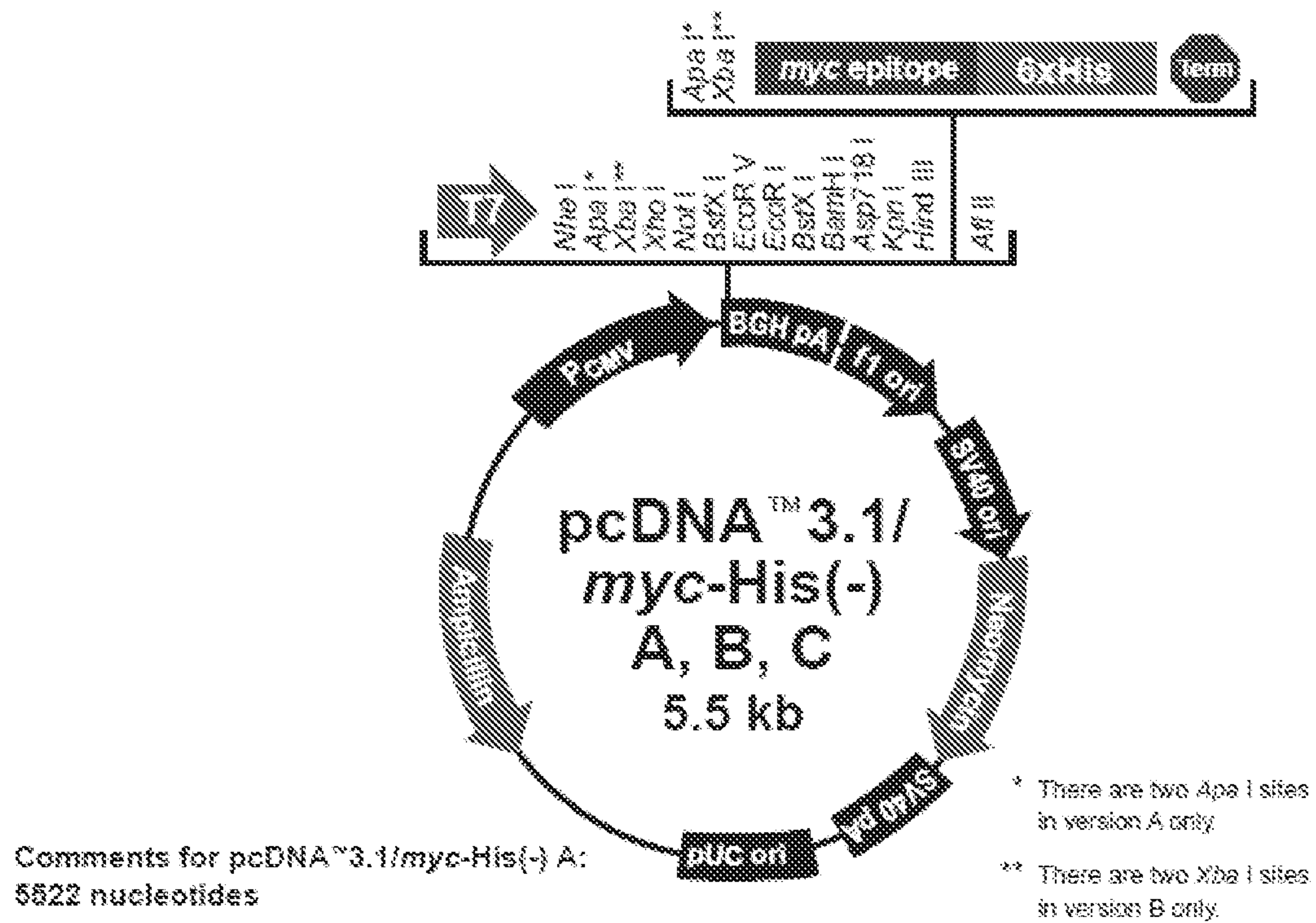
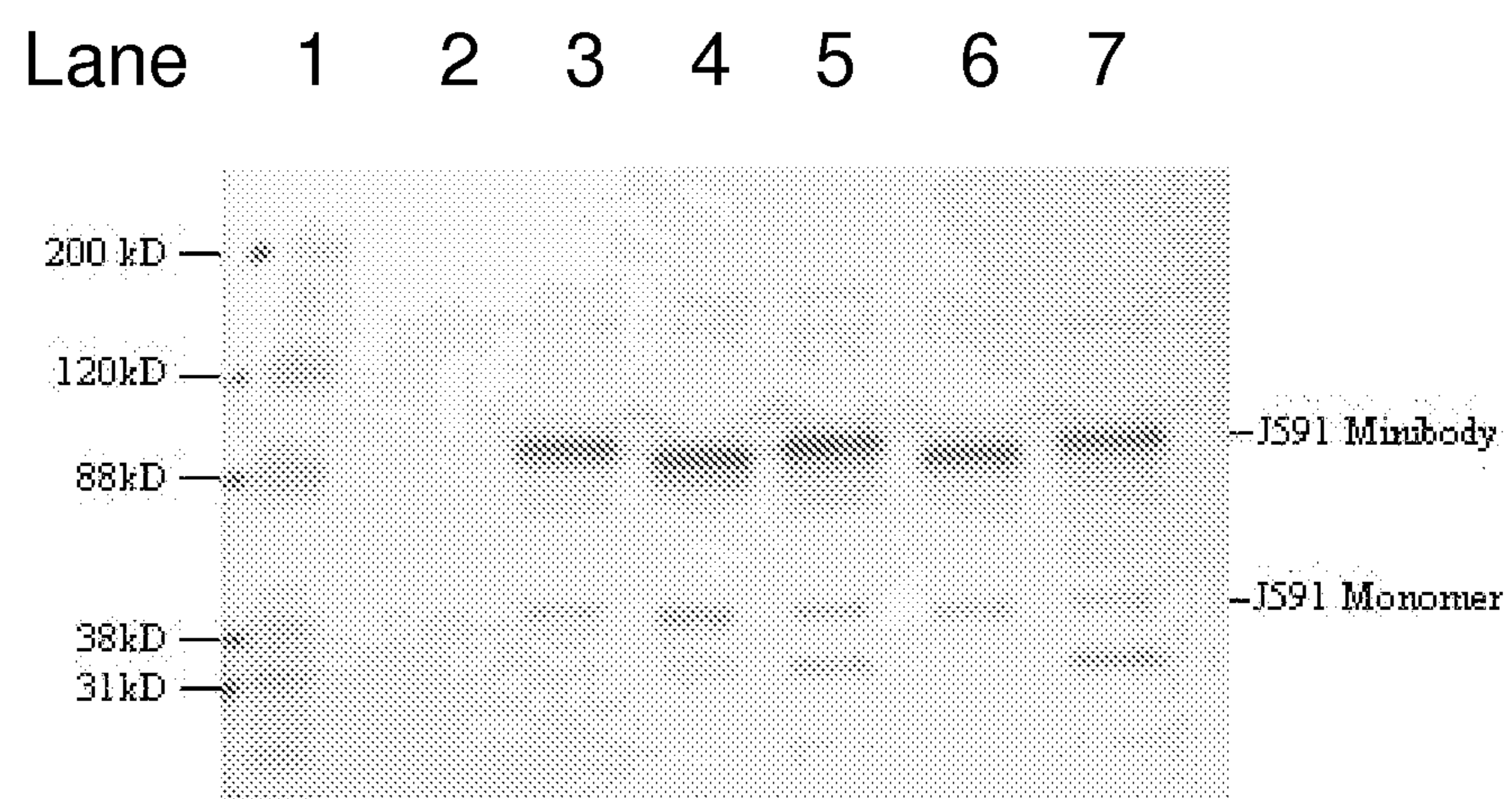
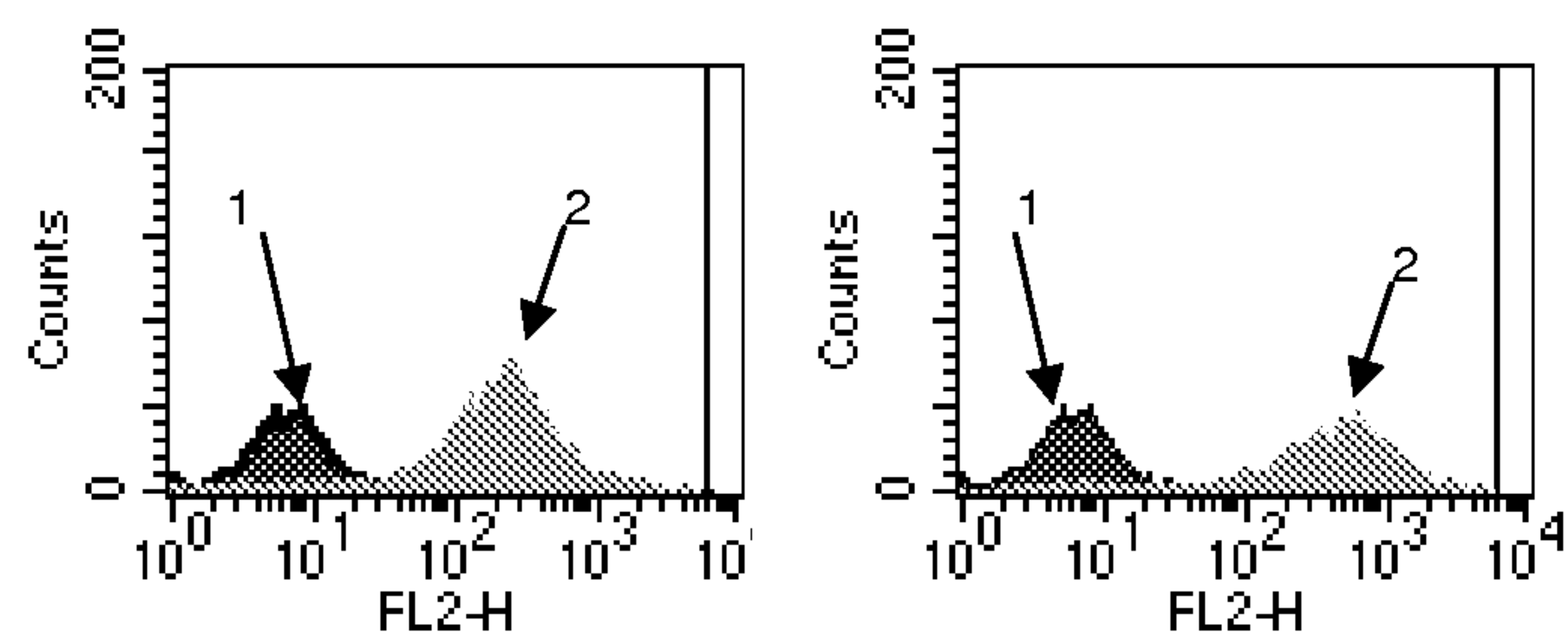


Fig. 10

**Fig. 11**

**A-** J591 HC VLVH Minibody    **B-** J591 HC VHVL Minibody



**C-** J591 2P VLVH Minibody    **D-** J591 2P VHVL Minibody

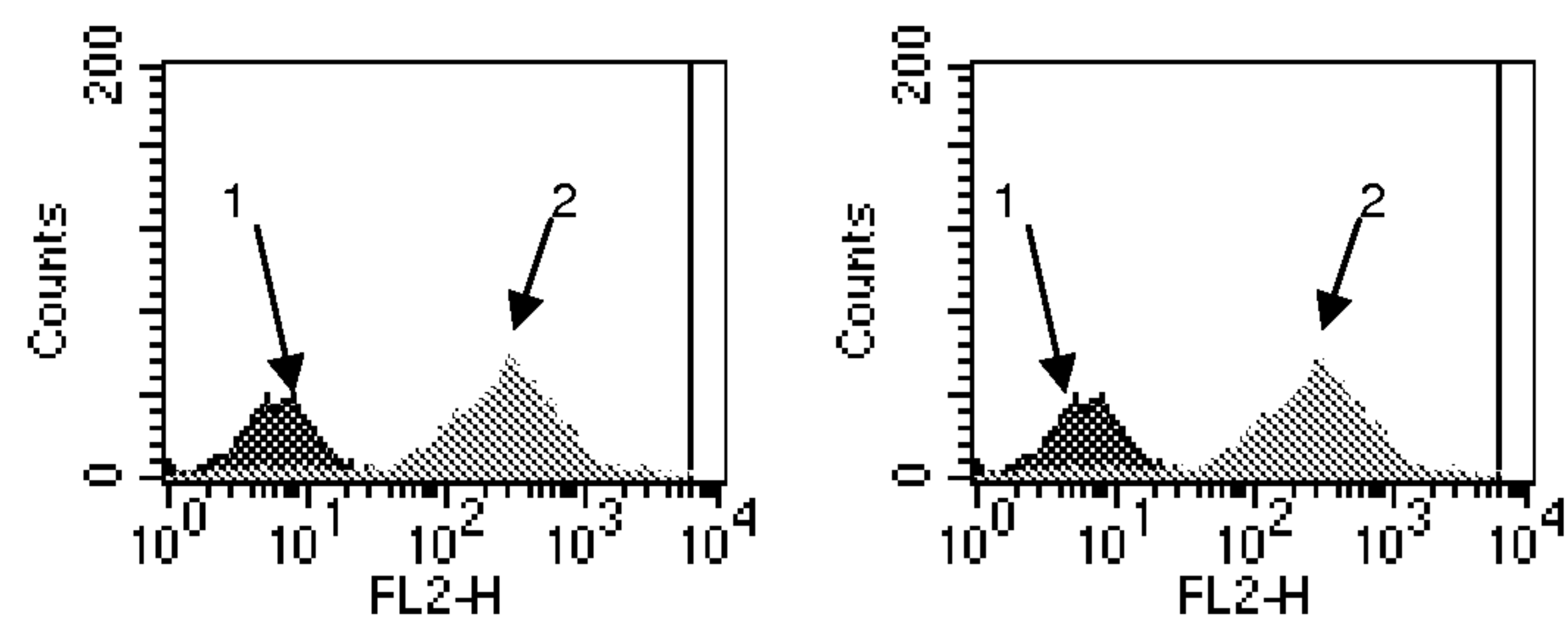
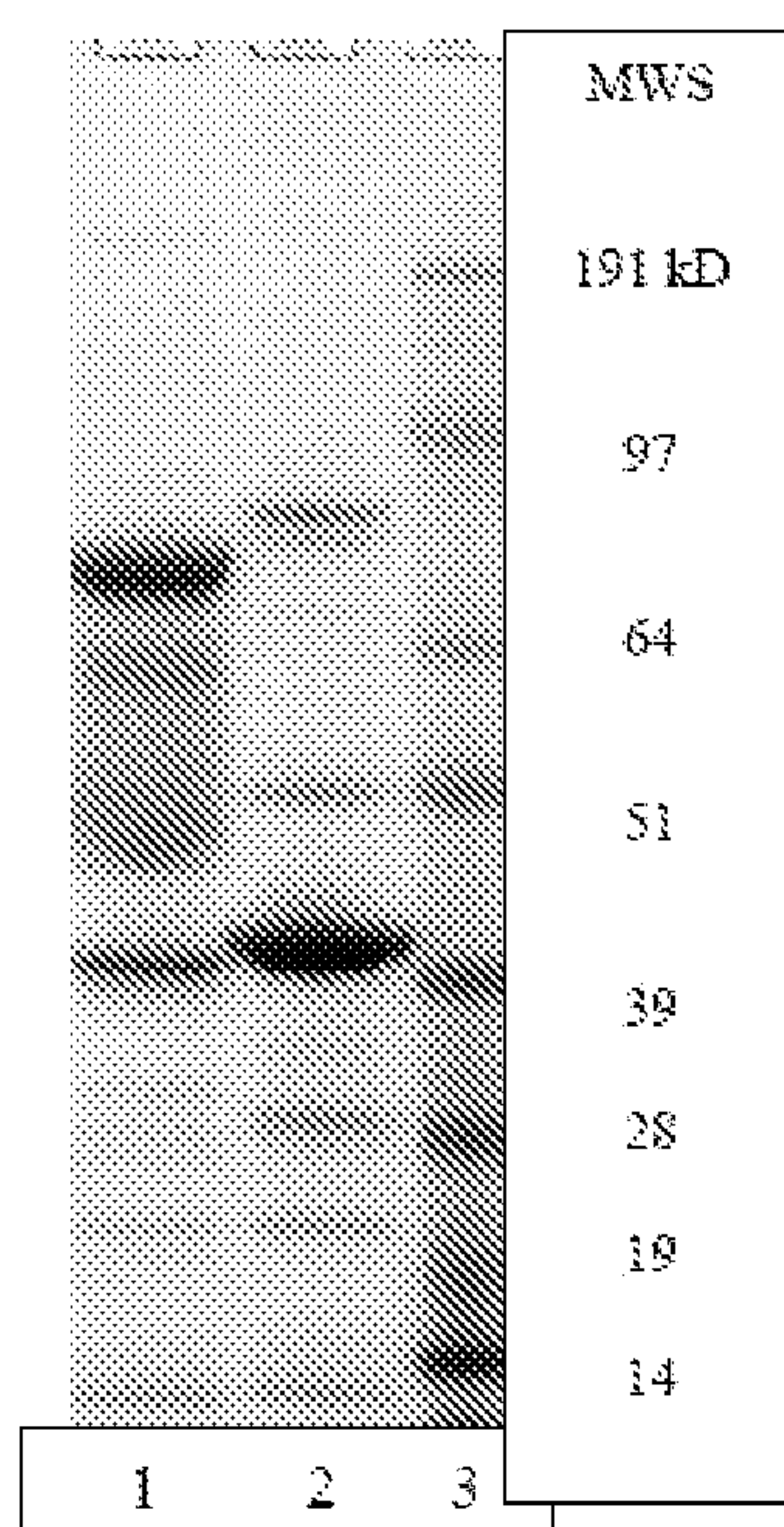
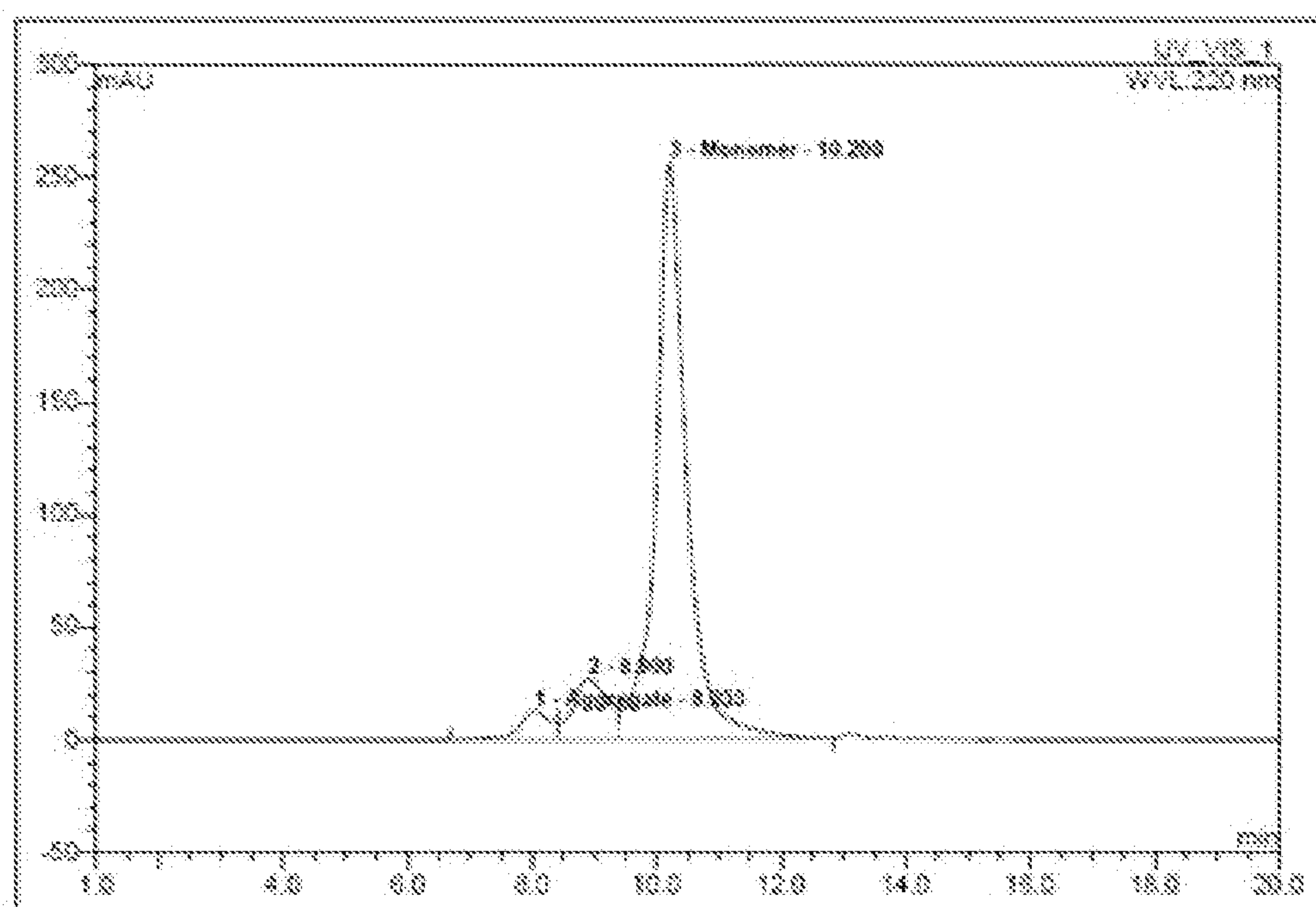


**Fig. 12**



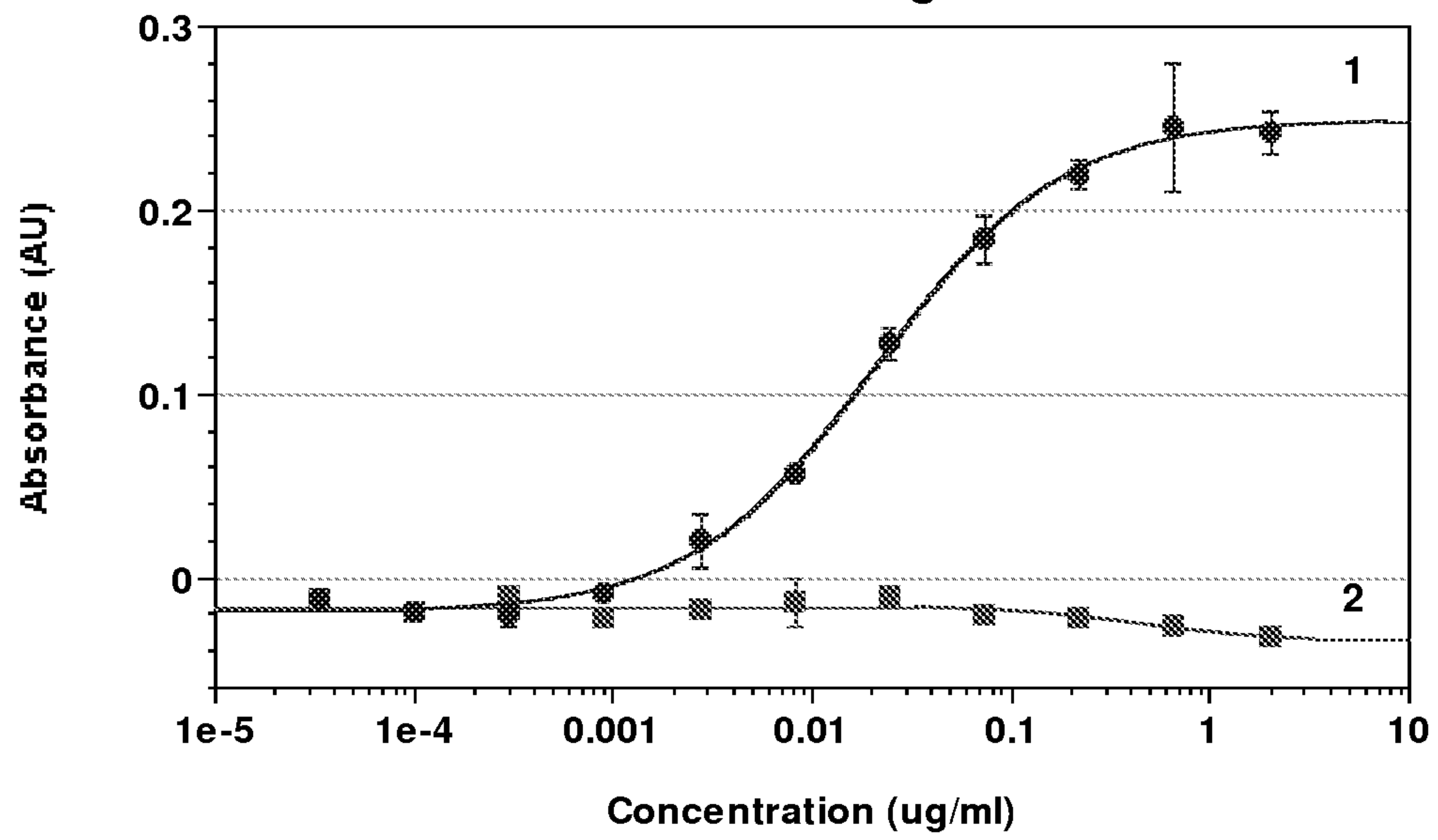
| Lane | Sample description          | Reducing Agent (μl) | Sample (μl) | 4X LDS | Amount loaded on gel (μl) |
|------|-----------------------------|---------------------|-------------|--------|---------------------------|
| 1    | Final product, 1:5 dilution | 0                   | 22.5        | 7.5    | 25                        |
| 2    | Final product, 1:5 dilution | 3                   | 22.5        | 7.5    | 25                        |
| 3    | Protein standards           | 0                   | 10          | 0      | 10                        |

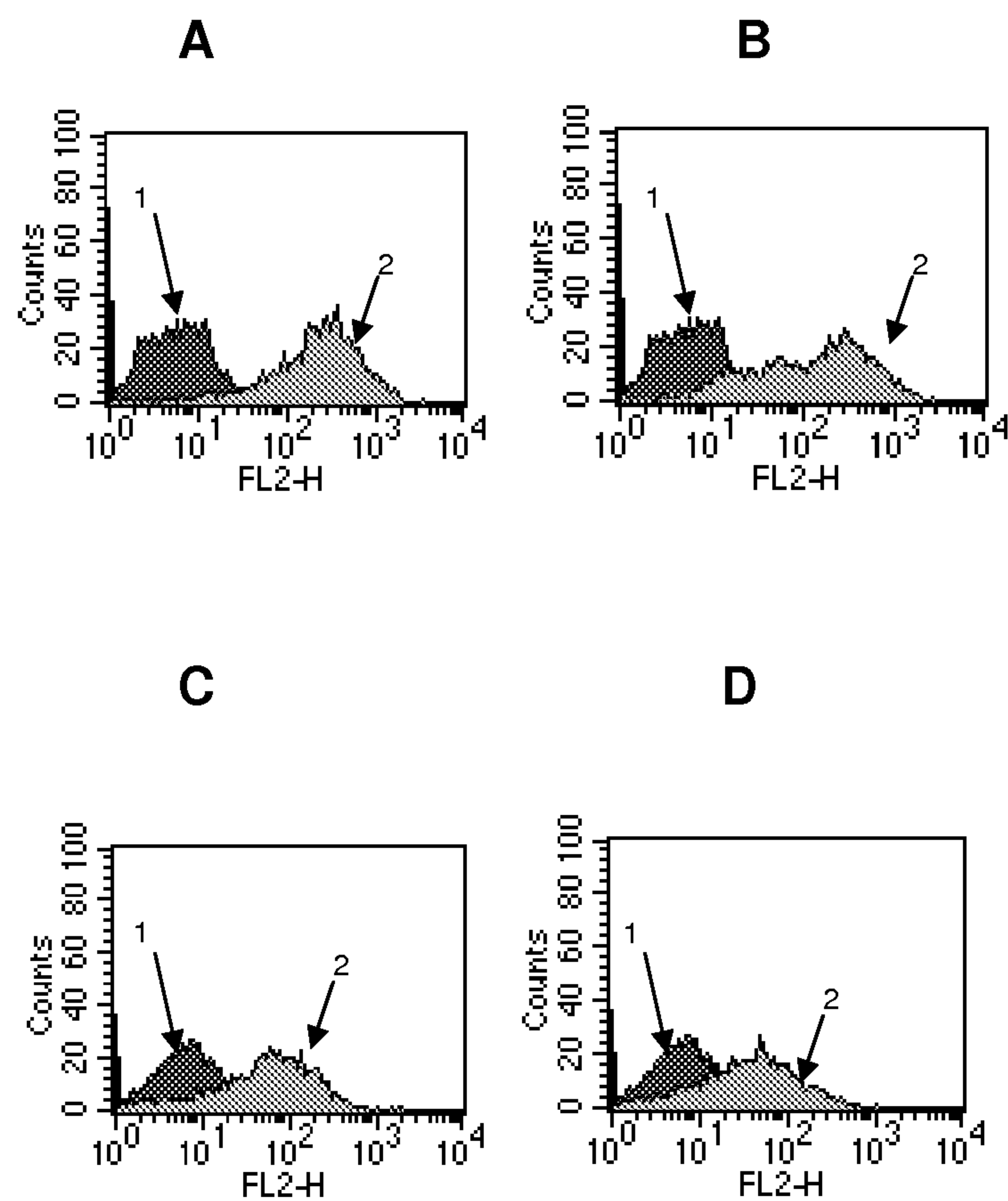
Fig. 13

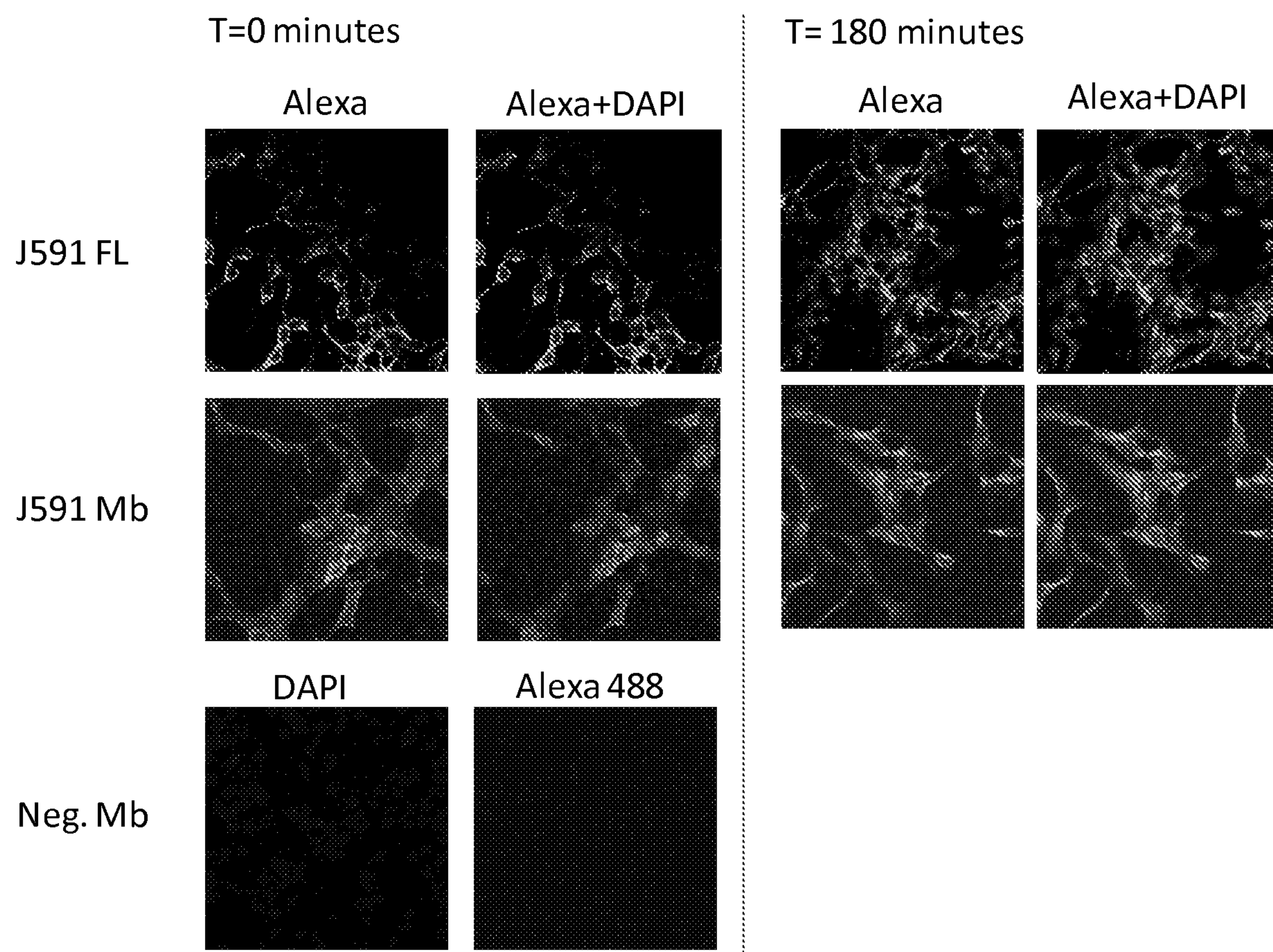


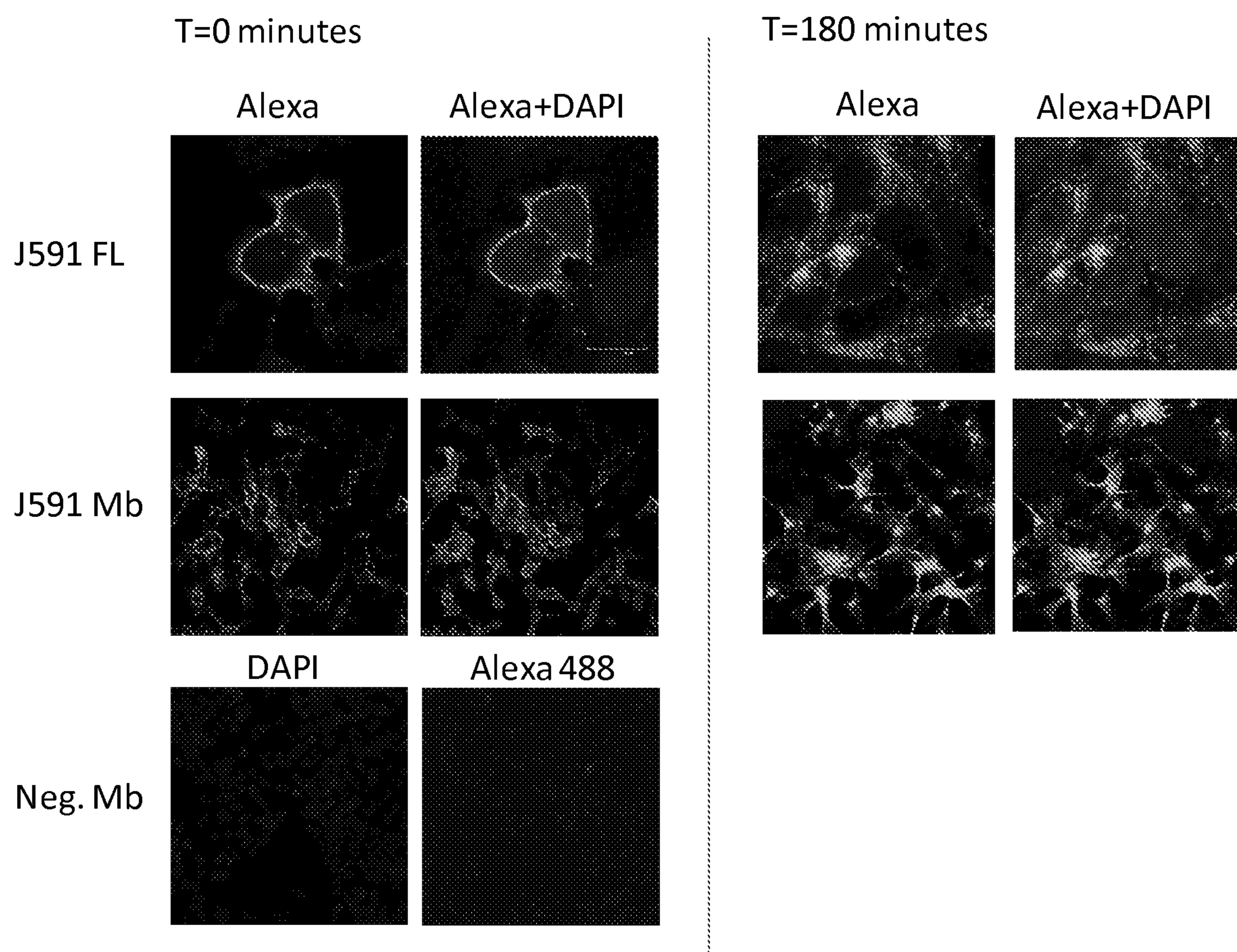
| Sample        | Aggregate (%) | Main peak (%) |
|---------------|---------------|---------------|
| Final Product | 14.64         | 85.36         |

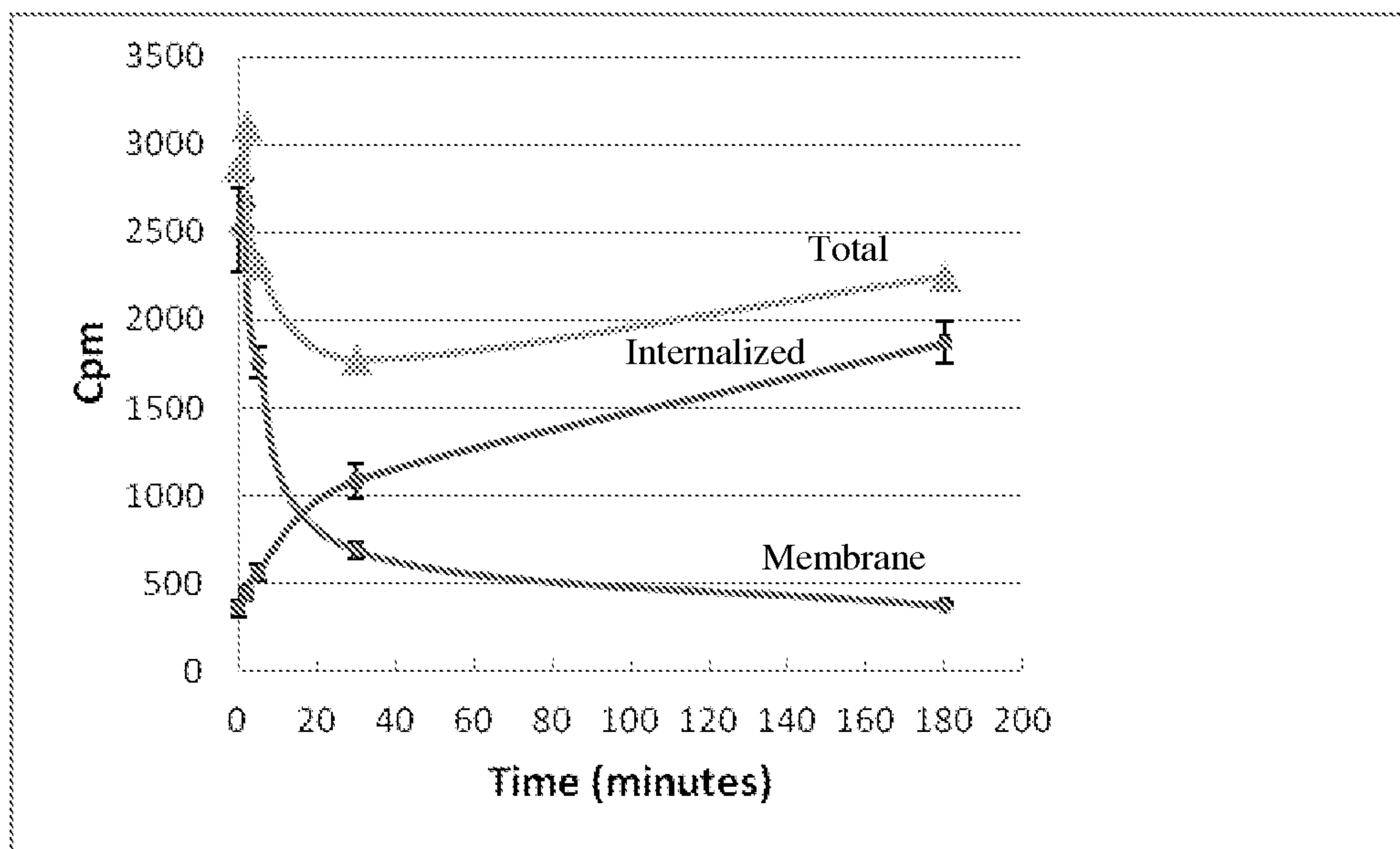
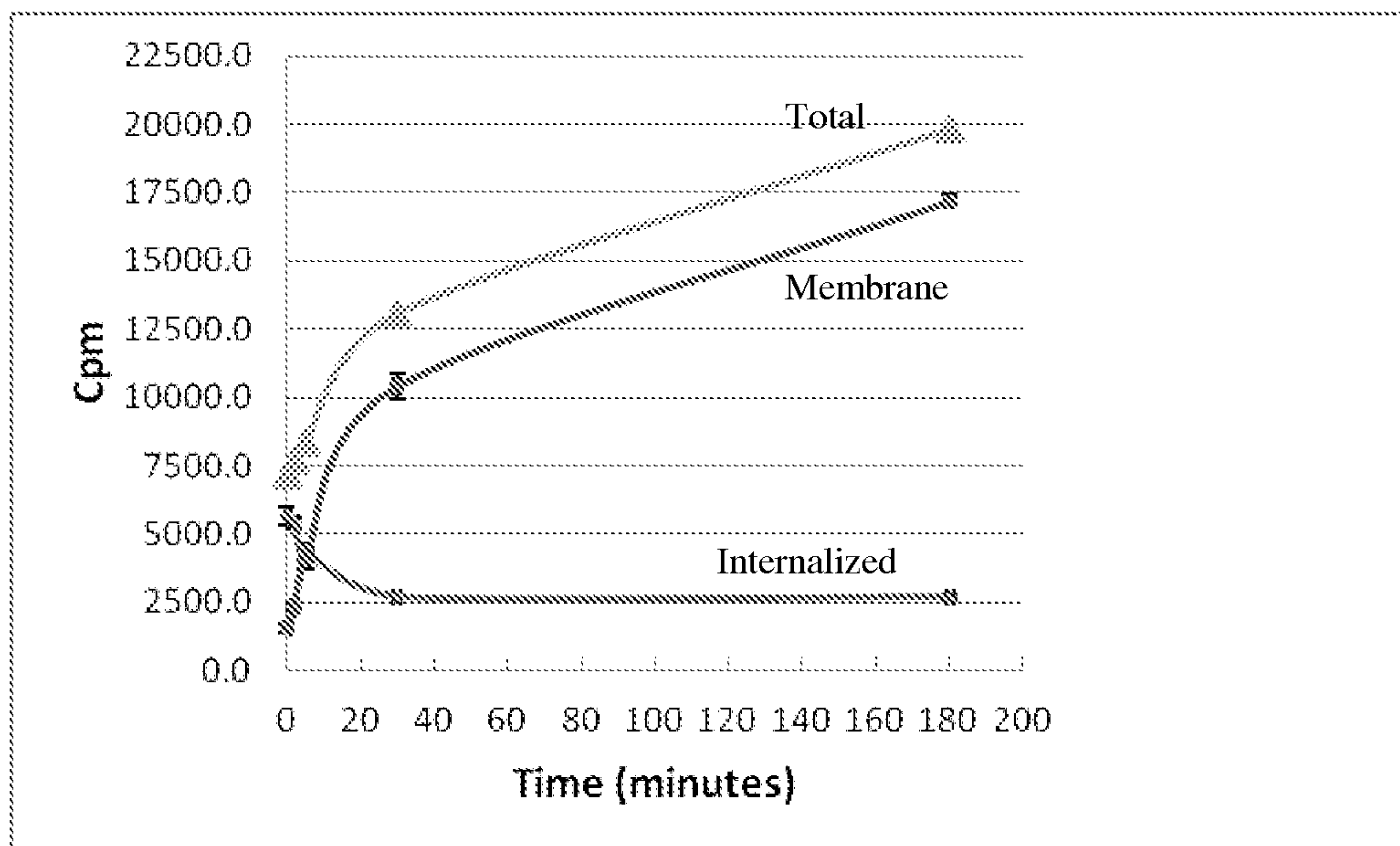
**Fig. 14**

**Fig. 15**

**Fig. 16**

**Fig. 17**

**Fig. 18**

**A****B****Fig. 19**

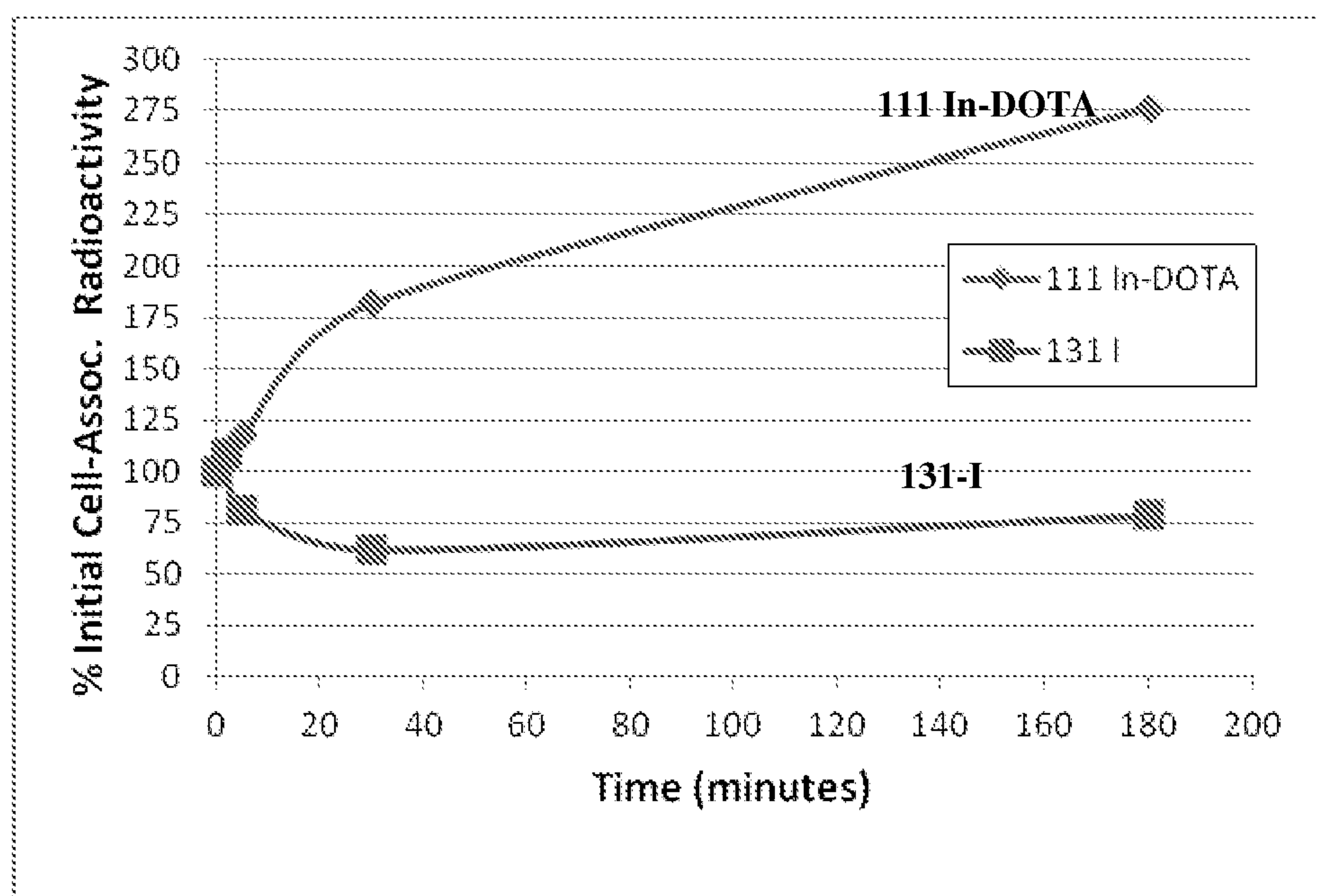


Fig. 20

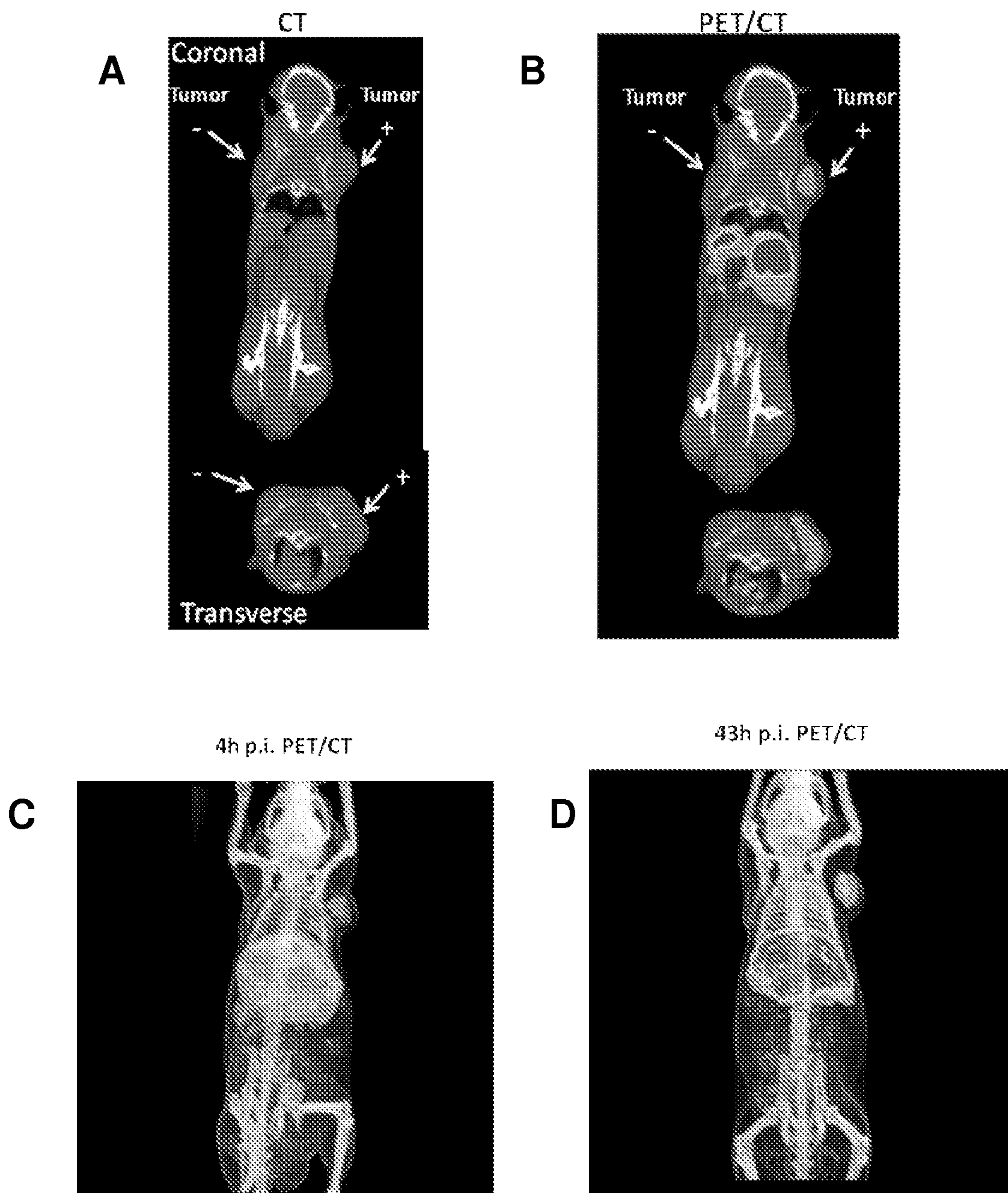


Fig. 21

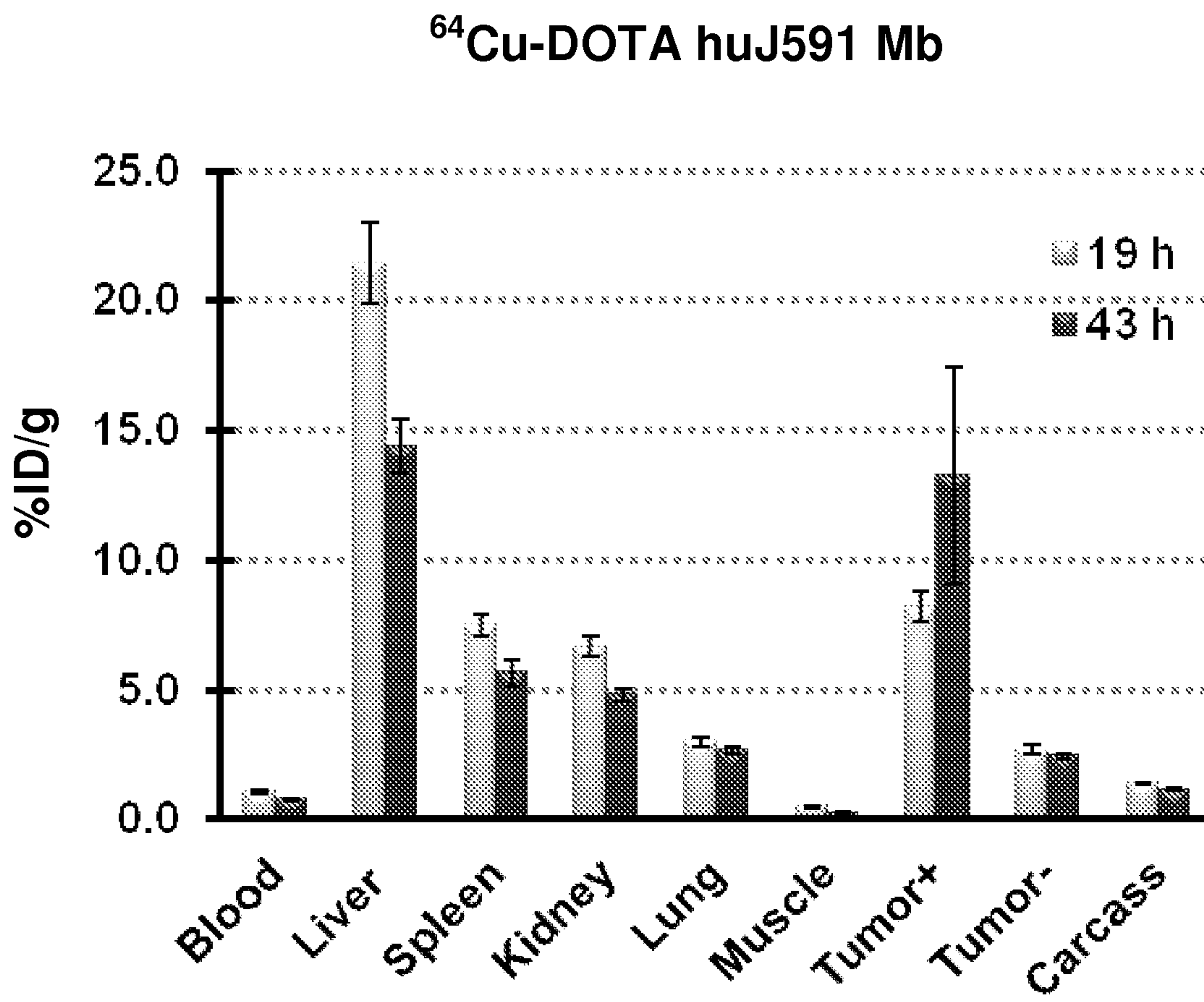
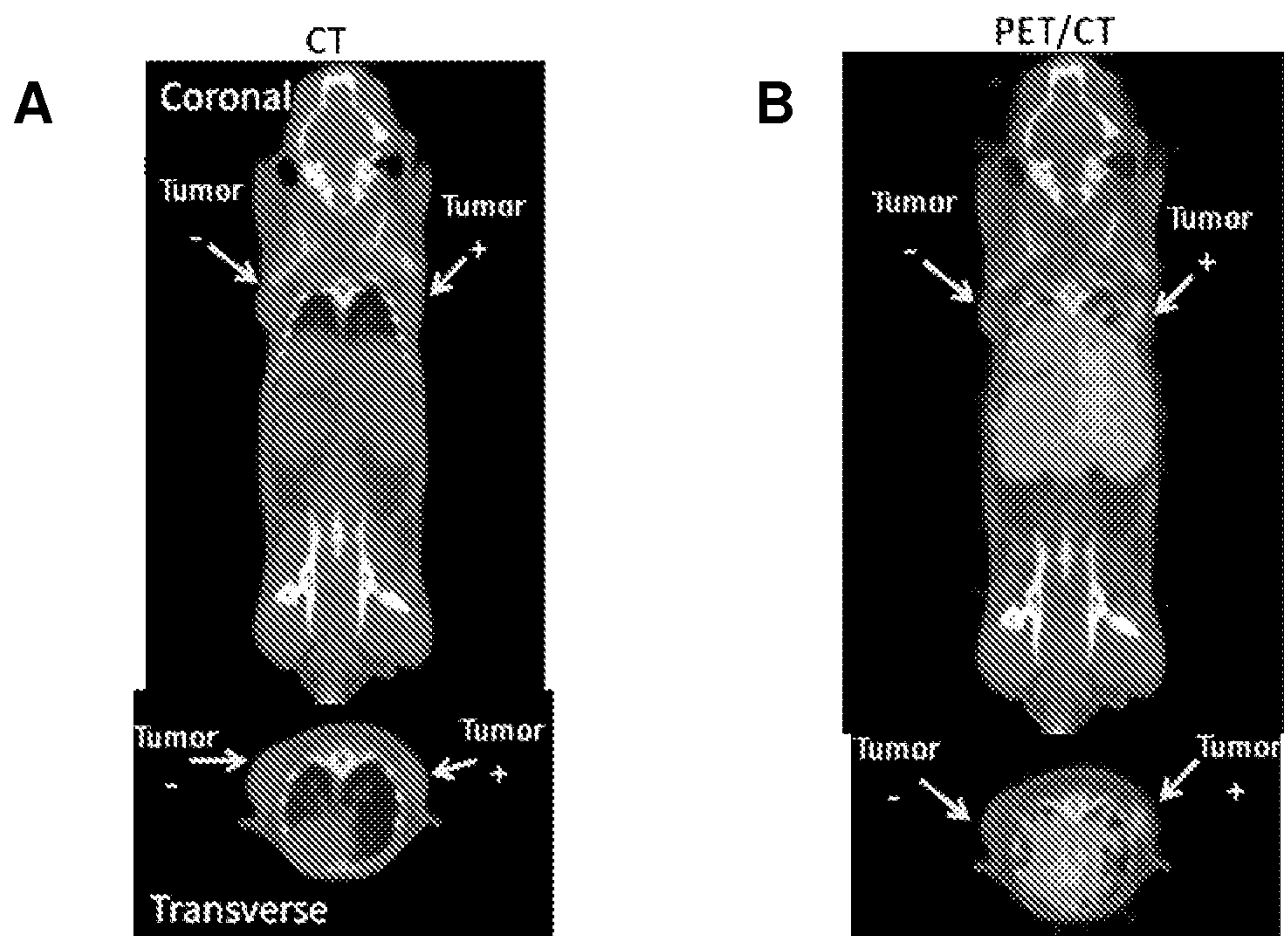


Fig. 22



### PET/CT Coronal sections

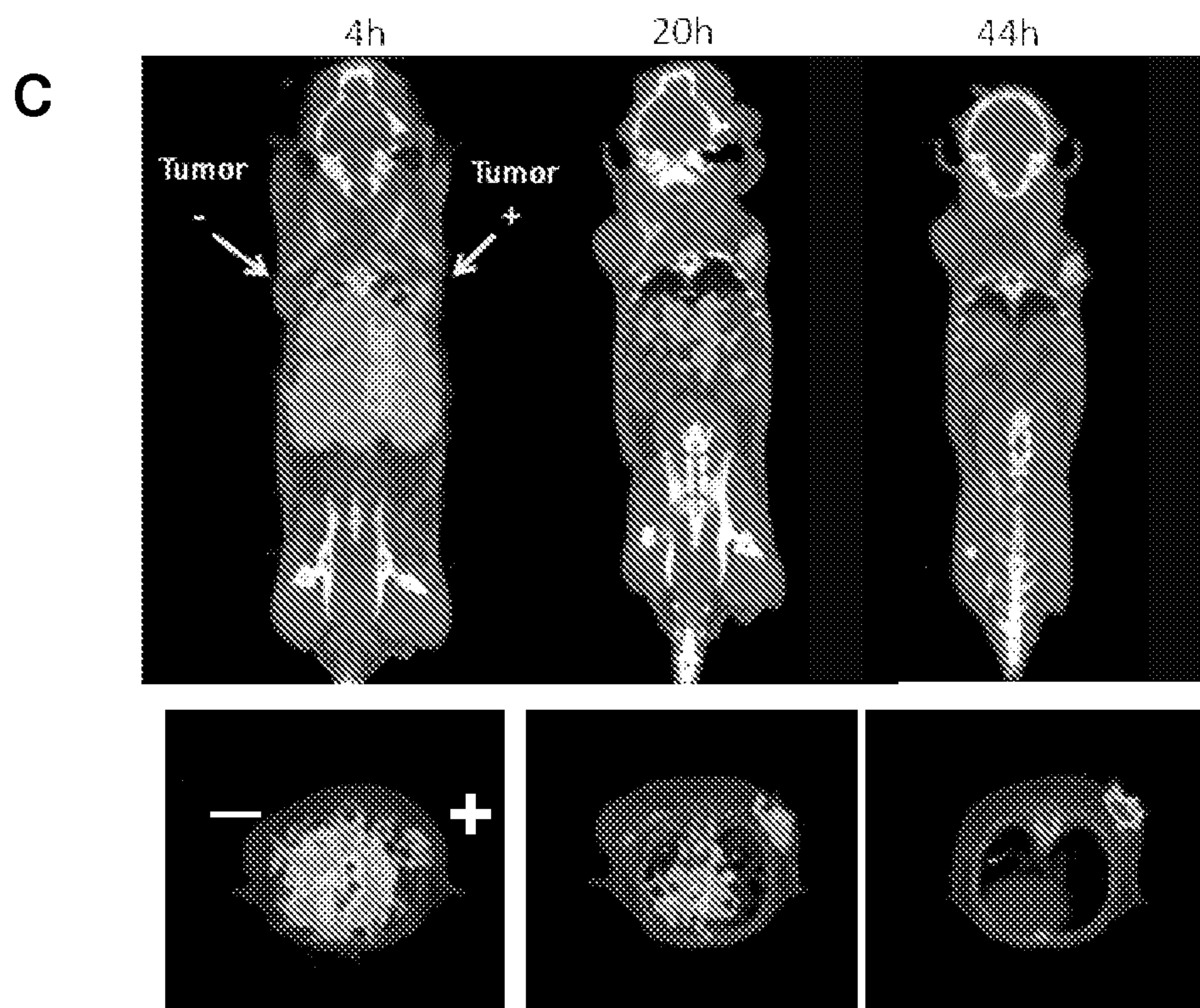
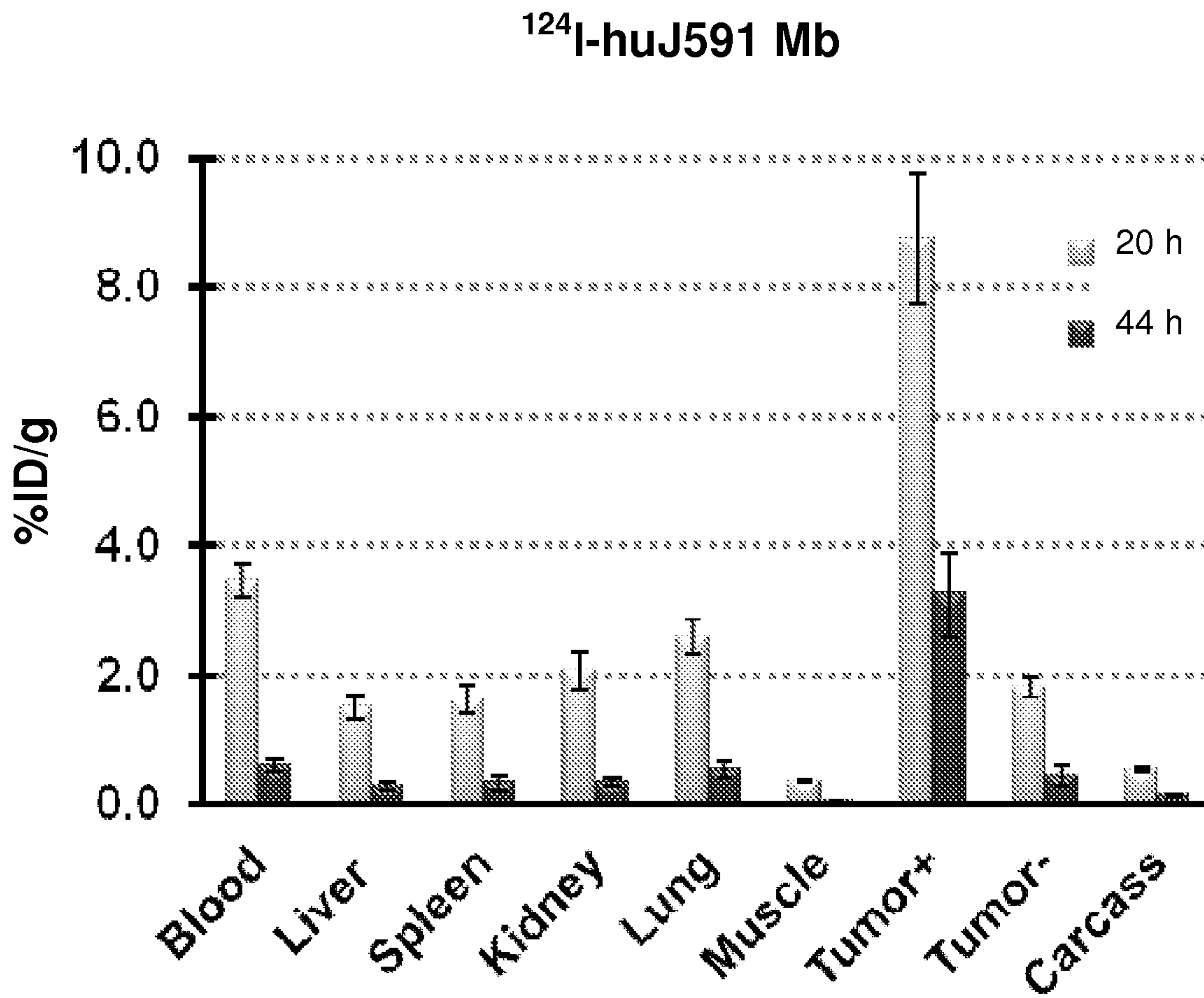


**Fig. 23**

**Fig. 24**

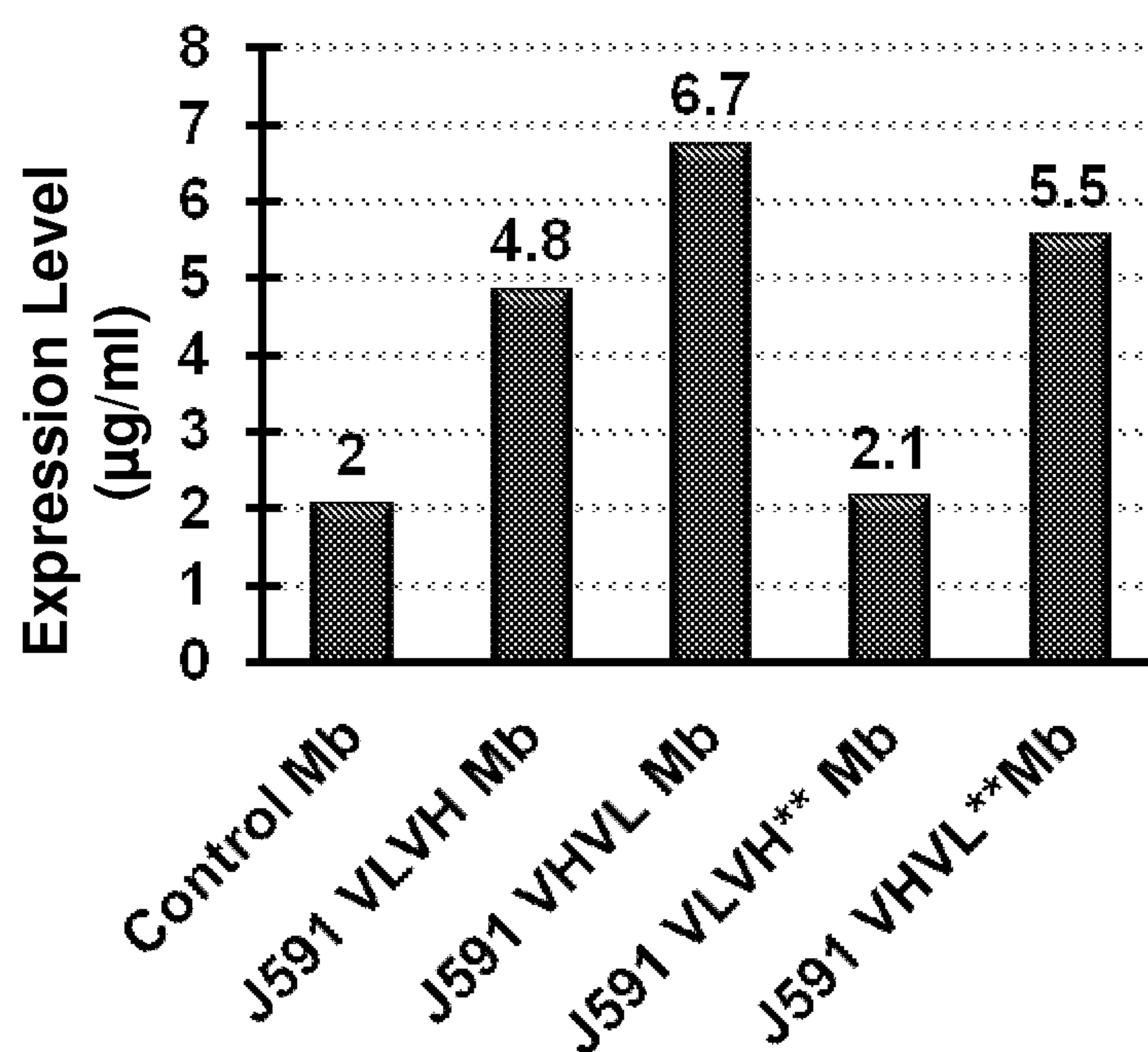
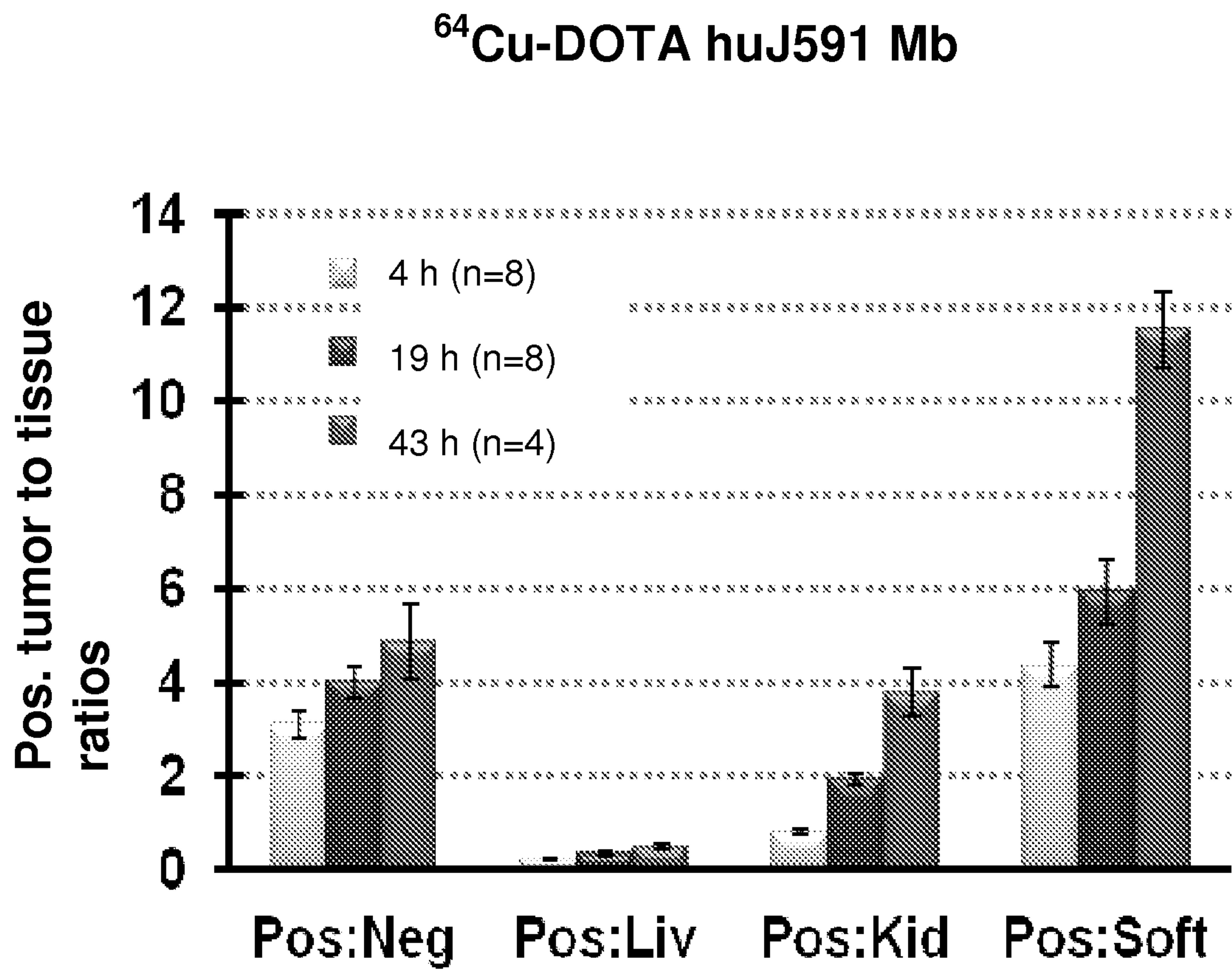
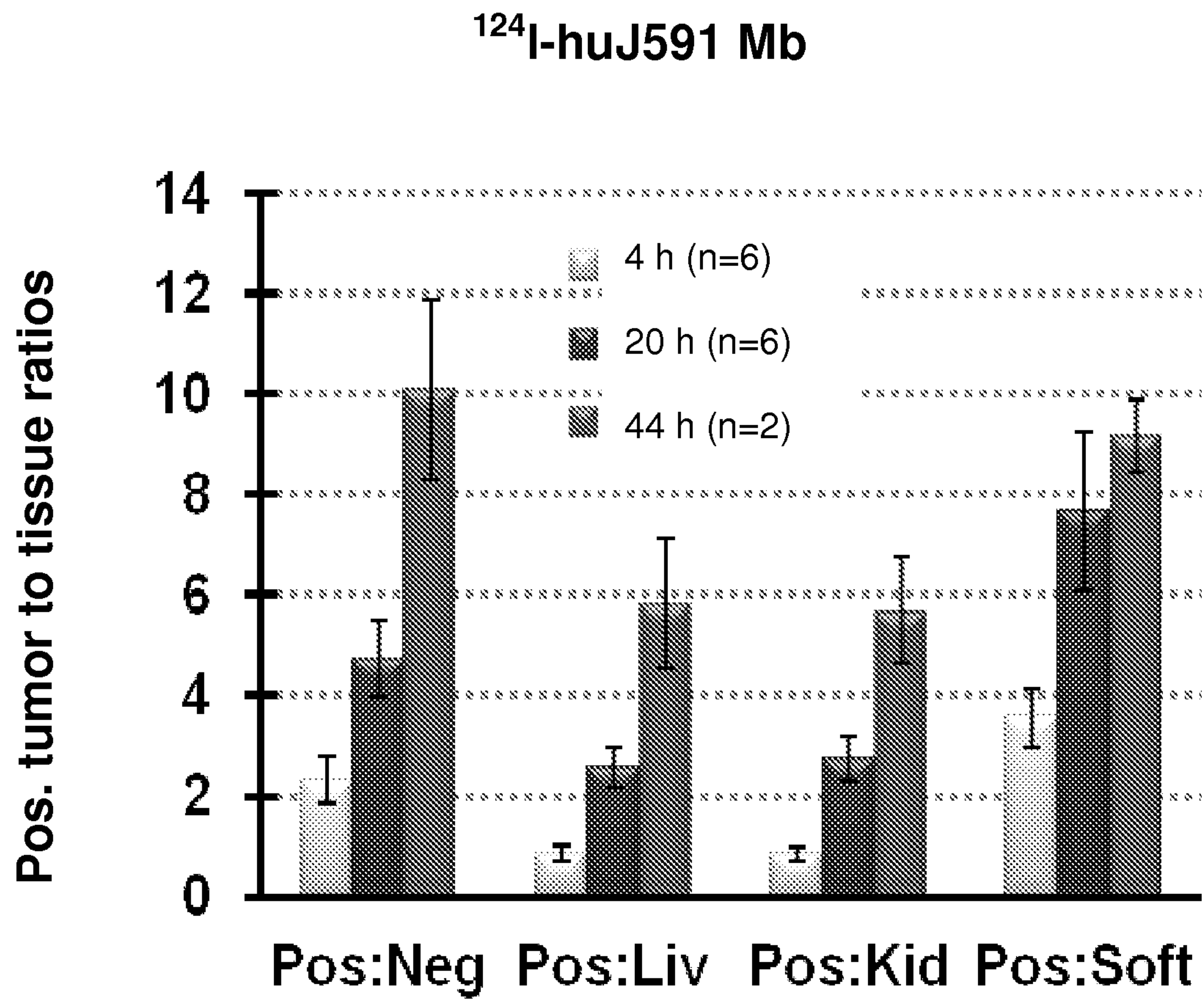


Fig. 25

**Fig. 26**

**Fig. 27**